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TECHNICAL-ECONOMIC STUDY OF SEWAGE SLUDGE DISPOSAL ON DEDICATED LAND

by

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16. ABSTRACT

This study documents the technical, cost, and environmental factors for disposing of sludge on dedicated land. Dedicated land is characterized by the practice of applying sludge on land where sludge disposal is the primary objective and other purposes such as improved crop yields or land renovation are secondary.

Three general types of dedicated land operations have been identifed:

Type I: Sludge is applied according to the nutrient needs of the crop. Cadmium application limits as specified by the U.S. Environmental Protection Agency (USEPA) are not exceeded.

Type II: Sludge is applied at rates that supply more than the crops' nutrient requirements and USEPA annual cadmium limitations are equaled or exceeded.

Type III: Sludge is applied at rates that greatly exceed crop nutrient requirements and annual USEPA cadmium limits are exceeded.

This study gathered information on six sites, two of each type described above to determine relative environmental impacts and costs.

This study indicates that well managed and properly used dedicated sludge application sites are environmentally acceptable even at high sludge application rates. Cost advantage between the three types of dedicated sites are difficult to determine because costs are dictated by local conditions, and institutional, social, political and aesthetic factors.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communication link between the researcher and the user community.

This report discusses some of the technical and economic factors, and advantages and disadvantages, in disposing of sewage sludge on dedicated land. Three types of sludge disposal on dedicated land are presented: (a) sludge applied to crops according to nutrient requirements with cadmium application rates limited by U.S. EPA criteria; (b) sludge application rates exceeding crop nutrient requirements and where allowable annual cadmium limitations are equalled or exceeded; and (c) sludge is applied at rates greatly exceeding crop nutrient requirements, and allowable annual cadmium limitations are also exceeded. Two sludge disposal dedicated land sites are discussed for each of the three nutrient and cadmium conditions (total of six dedicated sites). Measurable environmental changes at each site were evaluated using available environmental data. The economics of sludge disposal on dedicated land in both monetary and nonmonetary terms were also studied. Lastly, the advantages, disadvantages and other factors governing the disposal of sludge on dedicated sites were evaluated.

Francis T. Mayo, Director
Municipal Environmental Research
Laboratory

ABSTRACT

This study documents the technical, cost, and environmental factors for disposing of sludge on dedicated land. Dedicated land is characterized by the practice of applying sludge on land where sludge disposal is the primary objective and other purposes such as improved crop yields or land renovation are secondary.

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This study gathered information on six sites, two of each type described above to determine relative environmental impacts and costs.

This study indicates that well managed and properly used dedicated sludge application sites are environmentally acceptable even at high sludge application rates. Cost advantage between the three types of dedicated sites are difficult to determine because costs are dictated by local conditions, and institutional, social, political and aesthetic factors.

This report was submitted in partial fulfillment of Contract Number 68-03-3018 by PEER Consultants, Inc. under the sponsorship of the U.S. Environmental Protection Agency. This report covers the period of September 30, 1980 to September 30, 1981 and the study was completed as of May 1984.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

Conversion from metric to english units given in parentheses where appropriate.

BOD_5	--5-day biochemical oxygen demand
^{o}C	--degrees celcius
CEC	--Cation Exchange Capacity
cm (cm x 0.394 = inches)	--centimeter(s)
cm^3 (cm^3 x 0.061 = cubic inches)	--cubic centimeter(s)
cm/sec (cm/sec x 1.96 = feet/min)	--centimeter(s) per second
cnt/100ml	--counts per 100 milliliter(s)
DLD	--Dedicated Land Disposal
$/t/yr	--Dollar(s) per ton per year
E.C.	--electrical conductance
g	--grams(s)
g/cm	--gram(s) per centimeter
ha (ha x 2.47 = acres)	--hectare(s)
ha/hr	--hectare(s) per hour
hl (hl x 2.838 = bushel)	--hectoliter(s)
IEPA	--Illinois Environmental Protection Agency
IPCB	--Illinois Pollution Control Board
kg (kg x 2.20 = pounds)	--kilogram(s)
kg/ha (kg/ha x 0.89 = lb/acre)	--kilogram(s) per hectare
kg/t	--kilogram(s) per ton
km (km x 0.621 = miles)	--kilometer(s)
km/hr	--kilometer(s) per hour
l (l x 0.264 = gallons)	--liter(s)
m (m x 1.093 = yards)	--meter(s)
mm (mm x 0.03937 = inches)	--millimeter(s)
m^3 (m^3 x 1.307 = cubic yards)	--cubic meter(s)
m^3/d	--cubic meter(s) per day
μg/g (= mg/kg)	--microgram(s) per gram
mhos	--1/ohm(s)
μmhos/cm	--μmhos/centimeter
M&O	--maintenance and operations
meq	--milliequivalent(s)

ABBREVIATIONS (continued)

mg/l	--milligram(s) per liter
mg/kg (= μg/g)	--milligram(s)/kilogram
MJ (MJ x 948 = BTU)	--megajoule(s)
ml (ml x 0.264×10^{-3} = gallons)	--milliliter(s)
No.	--number(s)
NH_3-N	--ammonia nitrogen
NPDES	--National Pollution Discharge Elimination System
ppm	--parts per million
SRCSD	--Sacramento Regional County Sanitation District
SSD	--Springfield Sanitary District
TDS	--total dissolved solids
TKN	--total Kjeldahl nitrogen
TS	--total solids
TSS	--total suspended solids
t (t x 1.102 = ton (US))	--metric ton(s)
t/ha (t/ha x 0.446 = t/acre)	--metric ton(s) per hectare
t/ha/yr	--metric ton(s) per hectare per year
USEPA	--United States Environmental Protection Agency
V/V	--volume per volume
Vol.	--volume
WSW	--West-Southwest Sewage Treatment Works
yr	--year(s)

SYMBOLS

Al	--aluminum
Ca	--calcium
$CaCO_3$	--calcium carbonate
Cd	--cadmium
Cl	--chlorine
CN	--cyanide
Cr	--chromium
Cu	--copper
Fe	--iron
FeS	--iron pyrite
H	--hydrogen
Hg	--mercury
HCl	--hydrochloric acid
K	--potassium
K_2O	--potassium oxide
Mg	--magnesium
Mn	--manganese
N	--nitrogen

SYMBOLS (continued)

Na	--sodium
NH_3	--ammonia
Ni	--nickel
NO_2	--nitrite
NO_3	--nitrate
P	--phosphorus
PO_4	--phosphate
P_2O_5	--phosphorus pentoxide
Pb	--lead
%	--percent
Se	--selenium
Zn	--Zinc
$<$	--less than
$\geq$	--greater than or equal to

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SECTION 1

INTRODUCTION

BACKGROUND

Many municipal sewage treatment agencies apply some of their wastewater sludges to land to fertilize growing crops. Generally the amount of sludge applied depends on the nitrogen requirements of the crop(s), the cadmium application rate and other limitations as specified in the documents -"U.S. Environmental Protection Agency Regulations on Criteria for Classification of Solid Waste Disposal Facilities and Practices" (40 CFR 257 as corrected and amended); and relevant State regulations or requirements (1). Controlling the sludge application rate based on the crop nitrogen requirements protects groundwater supplies from possible nitrate contamination, and controlling a sludge application rate based on cadmium limitations prevents excessive uptake of cadmium in growing plants. The cadmium limitations in the Federal regulations generally apply to land which is to be used for the production of food-chain crops. Although nitrogen and cadmium are the elements of most frequent concern and are the principal criteria used in this report, other heavy metals, inorganic and organic toxic substances, nutrients, etc., could affect the land application of wastewater sludges.

Many communities have adopted a program of sludge application to land that is used primarily for sludge disposal; the growing of crops is incidental or nonexistent. In these cases, relatively large amounts of sludge may be applied resulting in excessive nitrogen rates and/or rates where the Federal criteria concerning cadmium application rates and quantities for food-chain crops could be exceeded. This type of operation may be termed sludge disposal. Usually the land where sludge is being applied is owned by the municipality, has limited public access, and is not intended for future sale. The land is therefore "dedicated" for sludge disposal. This concept was first developed as an informal practice in response to the need to reduce high operational costs associated with sludge disposal and this practice is accepted by regulatory authorities provided proper precautions are taken. Groundwater at dedicated sites must be protected by natural geological conditions or the site must be underdrained, and the drainage water must be treated before release. If crops are grown, they must be either of the non-food-chain type or meet the U.S. EPA criteria for animal feed (1).

The concept of "dedicated" land disposal of sewage sludge is subject to interpretation. At least three distinct variations of this concept are currently being practiced by municipal sewage agencies. These variations have been identified in this report as Type I, II and III and are described below.

Type I - Loading at Agronomic Rates

The sludge application rate is based on the nutrient needs (usually nitrogen) of the crop, but due to the metal concentrations in the sludge, cadmium application limits as specified in the U.S. EPA criteria (1) could eventually be exceeded. Depending on the metal concentrations in the sludge and the nutrient requirements of the crops being grown, applying sludge at agronomic rates may or may not result in excessive accumulations of heavy metals in the crops. If over a period of time there is a build up in heavy metals in the crops, the land would have to be considered "dedicated".

Type II - High Nutrient Application Rates

The sludge application rate provides nitrogen loadings that are greater than the nitrogen requirements of the crops. The application fields are either underdrained and drainage water is treated, or the drainage water is permitted to percolate to subterranean water supplies which are either not threatened or are not usable. Depending on the metal concentration in the sludge, there may or may not be an excessive accumulation of heavy metals in the crops.

Type III - Very High Sludge Application Rates

The sludge application rates greatly exceed those described in Type I and Type II, resulting in excessive cumulative application rates, i.e., short useful period for growing food-chain crops, and if crops are grown, they are non-food-chain or animal feed crops meeting EPA criteria. The application fields are underdrained to protect groundwater or drainage water is allowed to percolate to the groundwater which is either not threatened or not usable.

OBJECTIVES OF STUDY

The objectives of the study were:

1. Determine the costs associated with municipal sludge disposal on dedicated land.

2. Determine the technical and environmental advantages and disadvantages of sludge disposal on dedicated land.

3. Determine the aesthetic, social, institutional and regulatory aspects of sludge disposal on dedicated land.

METHODOLOGY

Site Selection

Six sites, two sites representing each type of the dedicated land disposal variations described above, were chosen for data collection and analysis based on the objectives of this study. Information for each of the sites was gathered using site visits. The choice of sites was determined primarily on the availability of costs and environmental data. The six selected sites are given in Table 1.

TABLE 1. SEWAGE SLUDGE DEDICATED LAND DISPOSAL SITES USED FOR TECHNICAL-ECONOMIC STUDY

Dedicated land disposal type category	Site location	Owner of site
I	Springfield, Ohio	Private
I	Toledo, Ohio	Private
II	Hanover Park, Illinois	Metropolitan Sanitary District of Greater Chicago
II	Springfield, Illinois	Springfield Sanitary District
III	Sacramento, California	Sacramento Regional County Sanitation District
III	Fulton County, Illinois	Metropolitan Sanitary District of Greater Chicago

Sites owned by municipal sewage agencies fitting exactly the Type I description and having cost and environmental monitoring data could not be located. It was determined that most municipalities employing dedicated land disposal apply sludge at the maximum rate possible within the limits of weather, soil type and application mode. However, two privately owned, Type I sites which most closely fitted the Type I description were selected. Those sites are located in Springfield and Toledo, Ohio.

The Springfield and Toledo, Ohio wastewater treatment plants apply sludge to privately owned tracts of land at rates that are not in excess of crop nitrogen requirements or the U.S. EPA annual cadmium application restrictions (1). Food-chain crops are produced on these sites, and are sold on the open market. Because the land tracts are privately owned, these sites probably do not fulfill the definition of dedicated land disposal, because the probability that the land may be sold at some later time does exist. The operations were included in this study, since they reflect the situation where municipal sludge is applied to privately owned land based upon crop nutrient needs, but eventually the U.S. EPA total cadmium application limits (based upon soil CEC) could be exceeded. Because the municipalities do not own the land, they can only comply with the U.S. EPA regulations by moving to new, privately owned tracts of land when the U.S. EPA cadmium limitations are reached. However, as part of a permit process, the land owner might have to agree to conditions which would restrict the land use or in effect "dedicate" the land.

The Springfield and Toledo operations, although having more cost information available than any other Type I sites considered for this study, do not have extensive monitoring information. This is mainly due to the nature of Type I sites. Sludge is applied at rates that will satisfy the U.S. EPA cadmium application restrictions and, therefore, crop and soil monitoring are not necessary. (Note: There may be a maximum cumulative application requirement). Also, because nutrient application amounts are being restricted to crop needs, the need for groundwater and surface water monitoring is also reduced. Thus Type I site operations do not utilize extensive environmental monitoring.

The Springfield and Toledo treatment plants are relatively small and do not have sophisticated systems for determining costs of individual programs such as sludge management. Toledo uses a private contractor's operation, and thus, transportation and actual application to land costs were not available. However, the total costs to the municipality were available. The Springfield operation while carried out on privately owned land is handled by the wastewater treatment plant personnel. The city owns and operates the sludge application equipment. The farmer receiving the sludge is responsible for the farming and harvesting operations.

The Type II sites are owned and operated by the municipal sewage agencies generating the sludge. These sites are adjacent to the treatment plants generating the sludge. At both sites, the sludge application rates exceed crop nutrient requirements and equal or exceed U.S. EPA annual cadmium application criteria. Corn is grown on the Hanover Park site for animal feed only, and no crops are harvested at the Springfield site. Costs and environmental data are available for both operations.

The Type III sites are also owned and operated by the municipal sewage agencies generating the sludge. At both sites, sludge is applied at rates greatly exceeding crop nitrogen requirements and in excess of U.S. EPA annual cadmium application criteria. The Fulton County site is owned and operated by the Metropolitan Sanitary District of Greater Chicago (District). The personnel working at the site, however, are under contract to the District and are not District employees. Corn is grown for animal feed only at the Fulton County site. The Sacramento Regional County Sanitation District (SRCSD) dedicated land disposal site is operated completely by the SRCSD and no crops are grown. Costs and environmental data are available for both sites, but the costs for the SRCSD operation are based on pilot data since the land disposal program was not fully operational when this study was made.

Technical and Economic Analysis

The technical feasibility of dedicated land disposal is governed by many factors. These include the availability of sufficient land and a number of site specific factors such as groundwater characteristics, topography, soil type, and climate. Desirable soil conditions include low permeability, minimal ponding, and freedom from boulders. Groundwater flow patterns should be such that no present or future domestic water supply wells can become contaminated. This noncontamination requirement may require selection of a site with an isolated groundwater pattern or with a low permeability surface and/or subsurface layer, which essentially prevents leachate from reaching the groundwater. Deviations from the conditions mentioned above might necessitate site modifications, such as construction of an artificial leachate control barrier, that could render dedicated land disposal, while technically feasible, an uneconomical option. All other appropriate environmental characteristics such as surface water quality, air quality, flood plains, etc., have to be considered.

The economic feasibility of sludge disposal on dedicated land must be determined in terms of both monetary and nonmonetary costs and benefits. The cost components include monies that are expended for capital and, operation and maintenance, as well as nonmonetary factors such as social and environmental impacts. Benefits include monetary factors such as revenues from crops grown, reduced operational costs, as well as nonquantifiable factors such as aesthetics, option reliability, or the ability to plan long term. Sludge disposal on dedicated land should be compared with other sludge disposal alternatives. The chief nonmonetary benefit of sludge application to dedicated land is the permanent feature which these facilities offer municipal agencies that must dispose of sludge. Other nonmonetary benefits could include erosion control resulting from reforestation or ground cover growth and aesthetic values of restoring vegetation to lands which have been degraded.

For the cost/benefit analysis performed in this study, monetary costs were calculated in terms of average annual values, while nonmonetary factors were accounted for descriptively to indicate their significance and impact. Nonmonetary costs included potentially negative environmental and public health impacts, and low public acceptance leading to poor public relations. Disposal of sludge on dedicated land can have adverse environmental impacts such as degradation of surface waters through leaching of soluble nutrients and toxic materials. Negative impacts relating to public health may include degradation of groundwater quality and potential for breeding insects and rodents, and odor generation. The measurable environmental changes at each site were evaluated using the available environmental monitoring data.

Another objective of this study was to assess the technical and economic advantages and disadvantages of the dedicated land disposal concept as a sludge disposal option. The advantages and disadvantages, and the factors influencing them, are very much dependant upon the particular dedicated land variation being considered. For example, land disposal costs could be partially offset by growing marketable crops at the disposal site; whether utilizing the land in this manner would result in a net decrease in overall disposal costs must be determined on a case by case basis. Using very high sludge application rates (Type III) has several advantages, including minimizing land requirements by maximizing application rates per hectare, increased flexibility in application rates and methods, etc. For this reason, advantages, disadvantages, and governing factors were assessed individually for each of the three dedicated land disposal variations.

Regulatory Constraints

Regulatory constraints on the application of sludge on land can be set by governments at the Federal, State, and local levels. At the Federal level, the U.S. EPA has issued regulations on criteria for classification of solid waste disposal facilities and practices (1). These regulations are summarized in Appendix A.

State and local governments' constraints may take place as laws, statutes, ordinances, guidance, land use restrictions, special permit conditions, criteria, standards, rules, regulations, etc. Each of the jurisdictions may have a different approach in controlling or regulating the land application of sludges. The approaches are apt to be very site specific and are described for each of the sites covered in this report.

SECTION 2

CONCLUSIONS

1. No evidence was found of adverse environmental impacts at the three types of dedicated municipal sludge application sites investigated. This result strongly suggests that well managed sludge-application-to-land projects can be environmentally acceptable regardless of application rate if properly sited, designed and operated.

2. The costs of the three types of sludge application to dedicated land sites studied were extremely variable and strongly influenced by local conditions. No cost advantage could be determined for any particular type of operation (Type I, II, or III), based on the costs of the six sites studied.

3. Selection of sludge management options for any community should be based on the relative information available for that community. At many of the sites, specific methods of operation were dictated less by cost than by social and aesthetic issues. For example, the use of sludge incorporation equipment at the two Type III sites was dictated by concern about odors and other aesthetics. Sludge incorporation is more aesthetically pleasing because the sludge applied cannot be seen (as, for example, in spray irrigation which is highly visible).

SECTION 3

DEDICATED LAND DISPOSAL TYPE I SITES

INTRODUCTION

The Type I category for dedicated land disposal of sewage sludge deviates somewhat from the overall concept of the dedicated land disposal option. Because the amount of sludge applied to the land in these operations conforms with both the crop nutrient requirements and Federal and State guidelines for cadmium and other metals, these sites probably cannot be used into perpetuity for sludge disposal. An advantage to a municipality is that it is not necessary to own the land, but a disadvantage is that similar sites must be continuously sought to dispose of sludge on a permanent basis.

The technical and economic feasibility of the Type I sites were determined using data obtained from the Springfield and Toledo, Ohio operations. Both sites are operated in conformance with both Federal and State guidelines for the application of sewage sludge to land for fertilizing growing crops that will be sold on the open market.

OHIO SLUDGE TO LAND GUIDELINES

In May 1976, the Cooperative Extension Service of Ohio State University issued a document entitled "Ohio Guide for Land Application of Sludge" (2). This document is informational and has no regulatory force. The document describes the basic factors needed for a successful sludge application to land project, but little in the way of specifics. However, the document does give specific information on sludge metal application rates to land. Table 2 shows the maximum amounts of metals in sludge that can be applied to an agricultural site using the Ohio Guide (2). Additionally, the Guide also recommends the following:

1. Sludges having cadmium levels of more than 25 μg/g (dry weight) should not be applied to farmland if the cadmium content is greater than 1.5 percent of the zinc content,
2. The yearly application of cadmium should be limited to 2.2 kg/ha, and
3. Soil pH should be maintained at 6.5 or greater.

TABLE 2. MAXIMUM AMOUNTS OF HEAVY METALS THAT CAN BE APPLIED TO LAND

Soil CEC (meq/100g)	Metal concentration (kg/ha)				
	Zinc	Copper	Nickel	Cadmium	Lead
0 - 5	280	140	56	5.6	560
5 - 15	560	280	112	11.2	1,120
> 15	1,120	560	224	22.4	2,240

Source: Ohio Cooperative Extension Service. Ohio Guide for Land Application of Sewage Sludge. Ohio State University, Columbus, Ohio, 1976.

SPRINGFIELD, OHIO LAND DISPOSAL OPERATION

Description of the Springfield Plant

The Springfield wastewater treatment plant is operated by the city of Springfield, Ohio. The plant began operations in 1935, and consisted of bar screens, grit removal, primary sedimentation, and mesophilic anaerobic sludge digestion followed by vacuum filtration for sludge dewatering. The dewatered sludge was disposed of in landfills. The treated wastewater effluent was released to the Mad River. In 1953, the plant capacity was increased and secondary treatment utilizing trickling filters was added to the treatment system which resulted in a suspended solids removal efficiency of 80 to 85 percent. In 1961, the plant was further enlarged to treat an average dry weather flow of 95,000 m^3/d. In 1972 two bar screens, two aerated grit chambers, and a chlorine building with a contact basin were installed. The vacuum filter sludge dewatering system has not been in service for many years. The Springfield, Ohio plant serves a population equivalent of 72,000 people. The design flow is 136,000 m^3/d, and the current average dry weather flow is 68,000 m^3/d. Springfield has a combined storm and sanitary sewer system.

The sludge solids from the primary and secondary settling tanks are stablized in a mesophilic primary anaerobic digester at 32 to 38°C for 30 days average digestion time, followed by a second stage digester operated at ambient temperature for sludge storage (30-day capacity) and thickening. The first stage digester includes a gas recovery system that supplies methane for heating the primary digesters and incinerating the screened materials. Figure 1 is a schematic of the Springfield wastewater treatment plant.

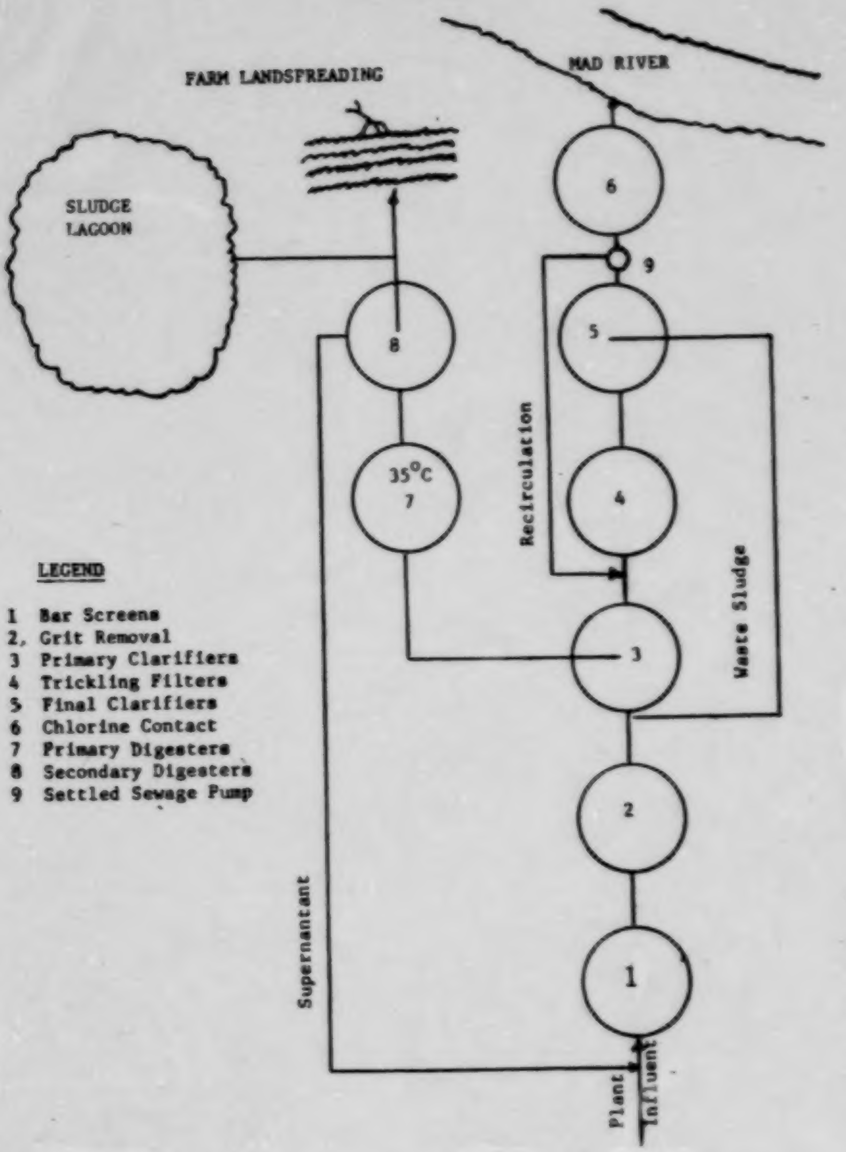
FARM LANDSPREADING
MAD RIVER
SLUDGE LAGOON
6
9
5
8
35°C
7
4
Recirculation
Waste Sludge
3
2
1
Supernantant
Plant Influent
LEGEND
1 Bar Screens
2, Grit Removal
3 Primary Clarifiers
4 Trickling Filters
5 Final Clarifiers
6 Chlorine Contact
7 Primary Digesters
8 Secondary Digesters
9 Settled Sewage Pump

Figure 1. Schematic of the Springfield, Ohio wastewater treatment facility.

The total annual sludge production is 1,088 dry, metric tons (t). Seventy percent of the plant's sludge is stored and dewatered in sludge lagoons. The lagooned sludge is used on public parklands, golf fairways, ballparks, and for landfill topping. The remaining 30 percent of the plant's sludge is used as fertilizer for growing crops.

Description of Farm Area

The farm area is located in Clark County, Ohio which has a temperate, humid climate with an annual average rainfall of approximately 96 cm. The average winter temperature is 11.3°C and the summer temperature is 24°C. The frost-free period averages 189 days/year. The area is a glacial drift with a heavy concentration of morainic materials, mostly gravel and sand or till, and underlain by limestone. The groundwater is at approximately 3 to 12 m depth. This area is gently rolling upland with good drainage. One farm is on Bellefontaine loam and silt loam. The soil analyses at the 0 to 15 cm depth, before sludge application, is shown in Table 3 (4). The crops normally grown in this county (in order of importance) are corn, soybeans, winter wheat and hay.

TABLE 3. SOIL ANALYSES FOR A COOPERATING FARM IN SPRINGFIELD, OHIO

pH (pH units)	Metal concentration				Base saturation			CEC
	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)	Ca (%)	Mg (%)	K (%)	(meq/ 100g)
6.6	141	437	3,990	696	67	20	3.8	13.0

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

One of the cooperating farmers received the first sludge delivery in 1980. Sludge is applied every third year at a rate of approximately 5 dry t/ha. The cation exchange capacity (CEC) of the soil is 13 meq/100g which, according to the Ohio sludge guidelines (2), allows a lifetime total application of 11.2 kg Cd/ha and 560 kg Zn/ha. Each sludge application adds 0.2 kg Cd/ha and 36.5 kg Zn/ha to the farm fields. Zinc is the controlling factor because the Ohio guidelines limit the total zinc application to 560 kg/ha which allows for 15 applications; whereas the cadmium limits would have permitted 56 sludge applications. The Ohio guidelines are more restrictive for this site than the U.S. EPA guidelines, since the latter sets no limit on total zinc application.

Environmental Response to Agricultural Uses of Sludge

Well or tile water monitoring is not required because sludge application rates are low (e.g., only 150 kg N/ha were applied in 1980) based on the definition of the Type I application rates. Soil samples are taken before and after sludge application. A typical analysis before sludge application of a soil sample from a Bellefontaine loam and silt loam soil is shown in Table 3.

Agricultural Uses of the Sludge

Since 1979, the Springfield wastewater treatment plant in cooperation with Ohio State University and the Ohio Farm Bureau Federation have been conducting a research study with cooperating farmers on the health and agronomic effects of applying sludge to fertilize cropland. In 1980, approximately 240 dry t of stabilized liquid sludge from the Springfield plant was applied to 47 ha of cropland. The sludge (5 to 8 percent solids) from the secondary digester was transported by 11.4 m^3 capacity tanker trucks owned by the city to the farmland. The transportation distance was 20 km roundtrip and the sludge was applied by gravity. The liquid digested sewage sludge averaged 3 percent nitrogen (N), of which 1.1 percent was ammonia nitrogen (NH_3-N), 1.8 percent phosphorus (P), and 0.5 percent potassium (K). The range of metal concentrations in the sludge is shown in Table 4 (3). This sludge met the Ohio guidelines for agricultural use, because the cadmium content was 0.5 percent of the zinc content, even though the cadmium concentrations exceeded 25 mg/kg.

TABLE 4. METAL ANALYSES OF SPRINGFIELD, OHIO DIGESTED SEWAGE SLUDGE APPLIED TO CROPLAND IN 1980*

Constituent	Maximum concentration (mg/kg)	Minimum concentration (mg/kg)	Mean concentration (mg/kg)
Cd	51	31	39
Cr	4,200	2,143	3,010
Cu	577	124	350
Pb	2,306	947	1,375
Ni	624	331	449
Zn	9,512	6,280	7,301

* Used by permission of City of Springfield, Ohio, Wastewater Treatment Plant.

Source: Springfield Water Department. Wastewater Treatment Annual Report for 1980. Springfield, Ohio, 1981.

Soybeans grown on sludge fertilized land yielded 4.17 t/ha in 1979. Soybeans grown on an adjoining field which received commercial inorganic fertilizer yielded 3.56 t/ha.

The Springfield, Ohio sludge utilization program is operating within the Ohio Guide for Land Application of Sewage Sludge (2). This sludge application is in compliance with the U.S. EPA Criteria (1). There are no restrictions on marketing the crops produced on these farms.

Public Acceptance

Springfield Ohio POTW has been applying stabilized sewage sludge on parklands, golf fairways, and other urban and rural sites for many years. A livestock health problem was reported on one farm where sludge had been applied. This case was investigated by the local and state health authorities and it was determined that the problem was not related to the use of sludge on this farm.

The cooperative project with the Ohio Farm Bureau Federation and the Ohio State University includes public meetings and other communication media to inform the citizens of the sludge utilization program. Should the Springfield wastewater treatment plant receive a complaint, a staff member visits the individual to hear the complaint and tries to correct the situation. Most farm sites are located away from any residential housing developments and there have been very few complaints in recent years.

Costs

In 1980, Springfield, Ohio applied 3,639 m^3 of 6.6 percent total solids sludge on 47 ha, using two 11.34 m^3 tanker trucks that traveled a total of 6,400 km. The average round trip was 20 km. This program involves six farms, four of which are in the cooperative sludge study. The annual and unit costs of this operation are presented in Table 5 (3).

The salaries in Table 5 are for two truck drivers, a laboratory technician for sludge analyses, an environmental technician to supervise sludge application on the land, and a maintenance supervisor.

Benefits to Farmer

The application of 5 t dry sludge/ha adds 150 kg N/ha, 206 kg P_2O_5/ha and 30 kg K_2O/ha to the soil. These nutrients would cost $244/ha if purchased in the form of chemical fertilizers. The farmer earned another $167/ha by the 0.61 t/ha increase in soybean yields. If one credits the value which the farmer receives, the cost of disposal is $55.60/ha or $11.12/dry t {($93.32 x 5 t/ha) - ($244/ha + $167/ha) = $55.60/ha}.

TABLE 5. ANNUAL AND UNIT COSTS FOR SLUDGE UTILIZATION AT SPRINGFIELD, OHIO IN 1980 (1980 DOLLARS)*

Cost item	Costs	
	Annual ($)	Unit **($/dry t)
Salaries	9,426	39.28
Overhead (70% of salaries)	6,598	27.49
Vehicle maintenance and fuel	2,729	11.37
Annual capital costs (2 trucks)	2,443	10.18
Pump maintenance and power	1,200	5.00
TOTAL	22,396	93.32

*Used by permission of City of Springfield, OH, Wastewater Treatment Plant.
**Based upon 240 metric tons dry solids per year.
Source: Springfield Water Department. Wastewater Treatment Annual Report for 1980. Springfield, Ohio, 1981.

Thus, this program benefits the private farmer by increasing the yields and reducing fertilizer costs, while providing an environmentally acceptable sludge management option to the Springfield Sanitary District.

TOLEDO, OHIO'S LAND DISPOSAL OPERATION

Description of the Bay View Wastewater Treatment Plant

The Bay View Wastewater Treatment Plant is operated by the city of Toledo. It has a design capacity of 386,000 m^3/d and treats an average dry weather flow of 322,000 m^3/d. The wastewater treatment operation consists of grit removal, primary settling, activated sludge treatment, and effluent chlorination. The primary sewage is treated with ferrous chloride (pickle liquor) to remove phosphorus. The primary sludge is digested in fixed dome anaerobic digesters at 35°C, with an average detention time of 29 days. The second stage digesters are operated at ambient temperatures and are used for storage and gravity thickening. The waste-activated sludge is aerated in isolated chambers before recycling to the head of the treatment plant. The digested sludge is also treated with lime and pickle liquor before it is dewatered by vacuum filtration. The incoming sludge to the digesters averages about 7 percent total solids content. The total sludge treatment produces about 45,000 t of sludge per year with a solids content of 22 percent (9,980 t of dry solids).

Description of Farm Area

Stabilized sludge from the Bay View plant is applied to farmland in Lucas, Wood, Fulton and Henry Counties. This region has an annual precipitation of 80 cm. The winters are cold with an average of 94 cm of snow. The summers are hot and humid, and 55 percent of the precipitation occurs during the period of April to September. This area consists of postglacial soils formed in a glacial-like landscape underlain by limestone bedrock. The water table is shallow, and most of the water-bearing bedrock is limestone. This region is level to very gently rolling. The soils were formed from glacial and related materials, and have a texture that ranges from sandy loam to clay loam (5,6). Much of the area requires tile or ditch drainage to maximize agricultural productivity. Corn is usually the first crop planted after sludge application. Other crops grown include soybeans and winter wheat. Winter wheat is harvested in mid-July after which the field becomes available for summer spreading of sludge.

Agricultural Uses of the Sludge

In the early 1970s Toledo began applying anaerobically digested sludge filter cake to land. This sludge was digested, dewatered by vacuum filtration with the aid of polymers and the sludge cake then applied on a limited amount of land. However, the sludge application to the site created problems for the city and the people near the farm site. The city chose landspreading of its sludge because it had no more space suitable for landfilling and incineration was undesirable.

The digested and dewatered sludge is now transported to the farm site by a fleet of six, 30 m^3 dump box trailers and two tractors, which are owned and operated by a private contractor. The trailers are equipped with two surge baffles and a top plate at the ends and the sides of the box. The trailer will withstand a panic stop at 80 km/hr without spillage of the sludge cake. The bottom edge of both sides of the boxes can be heated by the exhaust gases from the truck engine during the winter to prevent freezing. The Contractor also owns tractors that are used to deliver the sludge cake to the farm fields. Additionally, a rubber-tired end loader is used to load the field spreader. The average round trip to the farm site is 121 km. Sludge hauling is conducted 365 days per year except when interrupted by severe weather conditions. When sludge hauling is interrupted, the sludge cake is held in emergency storage with a capacity of no more than two days detention. Since 1978, the contractor has transported and applied stablized sludge from the Bay View plant to farmland in the nearest four counties of Lucas, Wood, Fulton, and Henry. The private contractor's operation is unique in that he sells most of the sludge cake to farmers on the basis of its nutrient content.

The sludge cake (22 percent solids content) is stockpiled at the application field at a transfer site usually for two to three days and at times up to two weeks prior to application. Winter sludge application (December through February) accounts for 25 percent of the annual sludge application operation. Sludge should not be applied on snow-covered, frozen sloping land unless there is adequate plant cover or residue to retard runoff (2). Winter spreading of sludge on frozen ground works well with up to 30 cm of snow. A problem of ice buildup on the bottom of the spreader bed can cause chain failure during the winter. The private contractor is developing a hydraulic ram spreader box which will eliminate the use of "live" bed chains.

An area of 16 ha is considered minimal for an economic operation and, larger fields are preferred. A number of all-weather field storage sites are provided at the application fields by placing 20 to 25 cm of crushed limestone near the public road. These sites are used when the fields are too soft for normal deliveries. After the stored sludge is spread on the farm field, the bed of limestone is also spread on the field and the storage area is deep plowed with a chisel.

The sludge cake applied to the farm fields is characterized in Table 6. The sludge is in compliance with the Ohio Sludge Guidelines and the U.S. EPA Guidelines for application to farmland. The farmer's interest in the purchase of sludge is based on the nutrients in the sludge. The contractor provides both a service and sludge to the farmer. Once the farmer decides to buy the sludge, a site report is prepared for the city of Toledo, the local health agency, the Ohio EPA and the farmer. This report includes the following information:

1. Name and address of farmer,
2. Crop to be grown,
3. Analyses of the surface and groundwater from the area used for sludge application, and
4. Analyses of the soil for pH, soil type, organic matter, macro- and micro-nutrients, and the metals common to sludge.

In addition, the farmer receives fertilizer recommendations.

The cost to the farmer for these services and the sludge at a field application rate of 11.2 dry t/ha dry sludge solids equivalent is $62/ha. The 11.2 dry t/ha sludge application provides approximately 230 kg N/ha, 740 kg total P_2O_5/ha (115 kg available P_2O_5/ha), and 15 kg K_2O/ha. Assuming the farmer's yield goal is 9.4 t/ha of corn, the 11.2 dry t/ha sludge application will supply the necessary N and P_2O_5 for most soils for the year of application and probably the P_2O_5 for the following three to five years. To maximize the benefits of sludge phosphorus and not exceed the cadmium standard, the sludge application is limited to once every six years. The Toledo sludge application rate of 11.2 t/ha once every six years adds 0.22 kg Cd/ha/yr to the fields which is below the Ohio and U.S. EPA Guidelines.

Most of the soils in this study area have a CEC between 5 and 15 meq/100g. The U.S. EPA cadmium restriction for the life of the site is 10 kg cadmium/ha. Therefore, sludge can be applied 45 times and if sludge application is just once every six years the site can be used for 270 years. However, a new site has to be found for each of the five consecutive years following the first sludge application. Based on a total annual sludge production of approximately 10,000 dry t, and an application rate of 11.2 t/ha, the first year's land requirements are 900 ha. Land demand for the next five years at 900 ha/year totals 4,500 ha. Thus, for continuous long-term operation of this program, the city of Toledo will require access to 5,400 ha of useable farmland, and will maintain the sludge application program at least for 270 years provided all the participating farmers continue to accept the sludge.

TABLE 6. CHARACTERISTICS OF TOLEDO, OHIO VACUUM FILTERED SLUDGE FROM 1976 TO JANUARY 1981 (Dry Weight Basis)

Parameter	Unit	Mean value	Parameter	Unit	Mean value
Density	g/cm^3	1.072	Hg	μg/g	1.79
Dry Solids*	%	21.89	Se	μg/g	21
Volatile Solids	%	35.56	Al	μg/g	5,862
pH	pH units	9.2	Fe*	%	8.07
Organic Matter	%	35.58	Oil & Grease	%	8.55
Total Kjeldahl N	%	2.064	PCB	μg/g	1.7
Nitrate	%	0.0504	DDT	μg/g	0.03
Ammonia	%	0.2018	Dieldrin	μg/g	0.03
Total P	μg/g	2,893	Chlordane	μg/g	0.1
Available P	%	0.4501	Aldrin	μg/g	0.03
K	μg/g	1,090	PBB	μg/g	0.05
Ca*	%	9.77	Lindane	μg/g	0.03
Mg	μg/g	7,598	Methoxychlor	μg/g	0.06
Cd	μg/g	19.82	2, 4-D	μg/g	0.15
Cr	μg/g	992	Heptachlor	μg/g	0.03
Cu	μg/g	508	Silvex	μg/g	0.05
Mn	μg/g	482	Endrin	μg/g	0.05
Ni	μg/g	49	Toxaphene	μg/g	0.6
Zn	μg/g	2,871	CEC	meq/100g	29.2
Mo	μg/g	15	Alkalinity*	μg/g	162,300
B	μg/g	19			
Pb	μg/g	592			

*Analyses performed on vacuum filtered cake (which receives high lime addition), not dry solids.

Environmental Response to Agricultural Uses of Sludge

Surface, tile, and well water samples are collected for chemical analysis by the Bay View Water Reclamation Plant staff before sludge is applied, and again the following spring. No contamination problems have been detected. A summary of sludge, soil, plant, and water analyses and their related costs are presented in Table 7. The sludge fertilized fields are sampled before application of sludge and during each growing season for the following three years. No soil problems have been observed from sludge fertilization. Plant tissue samples are collected by the contractor at pollination time.

TABLE 7. MONITORING PARAMETERS AND COSTS FOR THE TOLEDO SLUDGE UTILIZATION PROGRAM ON LAND PROJECT (1980 DOLLARS)

Monitored item	Parameters analyzed	Number of samples	Cost ($/year)
Sludge	K, N, NH_3, P, Total Solids, Volatile Solids, pH, and Density	52	11,284
Sludge	K, Ca, Mg, Cd, Cr, Cu, Mn, Ni, Zn, Mo, Pb, Hg, Se, Al, Fe and B	4	220
Water--well and surface	(NOT AVAILABLE FOR THIS REPORT)	250	35,000
Plant tissue	N, P, K, Ca, Mg, Zn, Mn, Cu, Fe, B, Ni, and Cd	70	9,800
Soil	Organic matter, CEC, pH, P, K,	125	12,125
Total Cost			68,429
Unit Cost ($/dry ton solids @ 10,000 dry t/yr)			6.86/t

The private contractor is spreading sludge within the limits of the Ohio Guidelines (2), and is also in compliance with the current U.S. EPA Guidelines (1). There are no marketing restrictions on the crops produced.

Public Acceptance

An early practice of storing and later spreading sludge on a small farm caused serious problems with the local citizens. The main complaints were related to odors and truck traffic. The problem continued until a court order stopped sludge application in Wood County. In later operations, sludge was spread on farm sites in four counties which convinced the residents of Wood County that a well-operated program does not create a public nuisance. The court order has been rescinded.

Citizen cooperation and support are vital to this type of sludge spreading operation and the public must be fully informed. The sludge storage sites could become an attraction to young children. This problem can be avoided by informing the local people and restricting access to the storage sites. The contractor's operation includes a street sweeper to clean the local roads and a water tank truck to clean the field equipment before it travels on the public roads. Such good neighbor policies go a long way to insure a problem-free operation. The fact that the farmer is paying for the sludge indicates confidence in the program to his neighbors. Also, the every sixth year sludge application rate over the four-county area ensures minimum truck traffic and field activities. Accurate media coverage and the support of qualified scientists are important to the success of the program. In recent years citizen objections to sludge usage on land have been minor.

Costs

In 1980, Toledo, Ohio produced 45,000 wet t of sludge at 22 percent solids which was trucked and spread on farms in four counties near Toledo. The city of Toledo paid approximately $13.40/wet t to a private contractor for trucking and land spreading of the sludge. The contractor is subject to unsteady sludge production schedules, cost-of-living increases, fuel, and labor rate adjustments. The cost of sludge processing for the city of Toledo is presented in Table 8. The cost for sludge dewatering at Toledo was $97.68/wet t which is somewhat higher than the cost of $75.20/wet t (1980 dollars) reported for mechanical dewatering by Zenz et al. (7). It is debatable whether the dewatering costs should be included in the total costs as shown in Table 8. However, the contract disposal costs are based upon using a dewatered cake and it is inappropriate to separate dewatering costs from total costs.

Benefits to the Farmer

Corn is usually the first crop grown after the application of sludge, with other commonly grown crops being soybeans and winter wheat following the

TABLE 8. ANNUAL AND UNIT COST FOR SLUDGE UTILIZATION ON LAND FOR THE CITY OF TOLEDO IN 1980 DOLLARS

Item	Costs	
	Annual ($)	*Unit ($/t)
Vacuum filtration		
**Amortization of:		
filtration equipment	34,200	3.43
building and auxilary equipment	17,800	1.78
Chemicals	132,000	13.22
M & O costs	790,950	79.25
Total dewatering cost	974,950	97.68
Contract Disposal+	674,500	67.58
Monitoring (from Table 7)	68,429	6.86
Total	1,717,879	172.12

* Based on 9,980 dry t/yr

** Amortization estimated from Zenz et. al. (7)

+ Contract for transporting and landspreading sludge cake produced at the Bay View plant (cost includes extras as specified).

corn harvest. The average corn yield in northwest Ohio is 9.4 t/ha (8) (Table 9). In the first year a farmer growing corn using sludge instead of chemical fertilizer in Wood County may save $123/ha for N and $42/ha for P_2O_5 (\$123/ha + \$42/ha - \$62/ha = \$103/ha) (Table 9). The farmer pays \$62/ha to the contractor for sludge application, therefore, the net saving to the farmer is \$103/ha. If the sludge furnished P_2O_5 for the next five crops, the P_2O_5 savings will total an additional \$210/ha. In summary, a net benefit of \$313/ha may be realized over a four-year period. This does not consider any worth for the K, Zn, Cu, or Ca supplied by the sludge. Therefore, the farmers are very interested in continuing with the spreading of sludge on cropland. Toledo is satisfied with its program of using sludge as a fertilizer on cropland. The present contractor has been doing a good job at a reasonable cost to the city. Toledo has no sludge disposal alternatives which are comparable either in cost or public acceptance.

TABLE 9. CORN PRODUCTION BUDGET FOR 9.4 METRIC TON PER HECTARES YIELD GOAL

Item	Quantity	Cost/unit ($)	Total cost/ha ($)
Corn yield	9.4 t/ha	130/t	1,222.00
VARIABLE COSTS			
Seed (kernels)	65,200kg	0.70/1000kg	45.00
Fertilizer			
N	224 kg/ha	0.55/kg	123.00
P_2O_5	63 kg/ha	0.66/kg	42.00
K_2O	76 kg/ha	0.33/kg	25.00
Lime	1.12 t/ha	11/t	12.30
Chemicals			
Atrazine	2.2 kg/ha	4/kg	8.80
Lasso	4.7 l/ha	4/l	22.00
Fuel, oil, grease			42.00
Drying - fuel & electric only			37.00
Trucking - fuel only			7.00
Repairs			40.00
Interest on operating capital (7 months) @ 12%			27.00
Miscellaneous			32.00
TOTAL VARIABLE COSTS			463.10
FIXED COSTS			
Labor charge (10 hrs @ $ 4.50/hr)			45.00
Machine & equipment charge			99.00
Land charge rent			296.00
Management charge, 5% of Gross			52.00
TOTAL FIXED COSTS			492.00
TOTAL COSTS			955.10
PROFIT			266.90

Source: Ohio Cooperative Extension Service. Ohio Crop Enterprise Budgets-Grain Forage. Ohio State University, Columbus, Ohio, 1981.

SECTION 4

DEDICATED LAND DISPOSAL TYPE II SITES

INTRODUCTION

Illinois Sludge Guidelines

The Illinois Environmental Protection Agency (IEPA) does not have documented guidelines for sludge on land disposal projects, but rather reviews each site on a site by site basis. State conditions, where applicable, are described for each site.

SPRINGFIELD, ILLINOIS LAND DISPOSAL OPERATION

Description of the Springfield Wastewater Treatment Plants and Sludge Disposal Operations

The Springfield Sanitary District (SSD) operates two wastewater treatment plants - Spring Creek and Sugar Creek. The Spring Creek plant was put into operation in 1928 and the Sugar Creek plant was started up in 1973.

Initially the Spring Creek plant sludge treatment consisted of anaerobic digestion of the combined primary and waste activated sludge and dewatering of the digested sludge on sand drying beds. The stabilized dewatered sludge was utilized by local farmers as a fertilizer and soil conditioner. Demand for the sludge exceeded the available supply. Increased labor costs in the 1950s made it uneconomical to continue removing sludge from the sand drying beds by hand. Shallow sludge lagoons were used for sludge dewatering and the sludge cake was removed by bulldozers. The sludge was still, however, in great demand by the local farmers. By the early 1960s a change in local farming practice resulted in little or no demand for the sludge. Commercial fertilizers were found to be a more convenient and economical alternative to sludge. It was then decided by the SSD that the sludge had to be disposed of on land owned by them. This was necessary if the SSD was to have a permanent outlet for the disposal of its sludge.

Because there was a need to determine the most efficient operation for sludge disposal on land, tests plots were established on the SSD plant grounds. Surface flooding was found to be an unsatisfactory method of liquid sludge application. Even with solids concentrations of five or six percent, the sludge would run down a slight slope with uneven distribution on the test plot. Due to the low permeability of the soil, it was difficult for the sludge to dry properly between successive liquid applications. Underdrains were apparently needed before reasonable application rates could be utilized. Lagooning was unsatisfactory for storing liquid sludge because the sludge solids settled to the bottom of the lagoon and these solids were difficult to remove even with utilization of air mixing and other procedures. Eventually, after the testing in the 1960s, a sludge disposal system was designed that used spray application of liquid sludge without lagooning on underdrained land owned by the SSD. This sludge application system was adopted for the existing Spring Creek plant and for the Sugar Creek plant described below.

In 1973, the SSD began operation of its new Sugar Creek plant. With the construction of this plant, the SSD had two wastewater treatment plants under its jurisdiction. The Sugar Creek plant has an average dry weather flow capacity of 37,854 m^3/d with a hydraulic capacity of 378,540 m^3/d (9). The wastewater treatment plant consists of grit chambers followed by contact stabilization (four hours contact, eight hours reaeration). The plant does not use primary settling tanks. The contact stabilization plant effluent is stored in a two-day detention earthen tertiary treatment pond. The effluent from the tertiary treatment pond is chlorinated in a small earthen contact basin located within the tertiary pond itself before it is discharged to the Sangamon River. The plant has a National Pollution Discharge Elimination System (NPDES) permit which requires final effluent limits of 10 mg/l for BOD_5, 12 mg/l for total suspended solids, 1.5 mg/l for ammonia nitrogen and, fecal coliform of 400 cnt/100ml (Membrane Filtration). The Sugar Creek treatment plant is equipped with circular stormwater settling tanks, the contents of which also flow to the tertiary treatment pond.

The raw sludge from the contact stabilization basins and the stormwater settling tanks are combined and treated by aerobic digestion tanks having a capacity of 6.06 x 10^6 liters. Detention time in the aerobic digester is about 14 days. The average total solids leaving the aerobic digester is about one to two percent (10). The aerobically digested sludge from the Sugar Creek plant is disposed of by soil application on a 14.56 ha site contiguous to the wastewater treatment plant and owned by the SSD. A fixed 15.2 cm diameter cast iron force main is used for spray irrigation of the sludge. The force main is buried and valved so that it can be utilized for liquid sludge application during the winter without freezing. The force main is laid on a slope to allow drainage of the liquid sludge back to the sludge pumping station wet well and return contact stabilization aeration tank following each sludge application. During the 1973-74 winter, sludge was sprayed when the ambient temperature was -24°C with no freezing problems (9). The ability to apply sludge during the winter negates the need for lagoon storage of sludge at the Sugar Creek plant. The sludge application site is underdrained with perforated PVC pipe. Underdrainage and drainage from the forced main are pumped back to the wastewater treatment plant.

Geology of the Site

The soil surface layer that covers the Sugar Creek land disposal site can be described as a dark grey, very fine sandy, silty clay to a silty clay about one to two meters thick and grades from an alluvial deposit near the surface to one of windblown origin with depth. Below the surface mantle for a distance of about four meters is a silty loess. Groundwater is encountered within the lowest portion of this layer (about 4.0 m). Underlying the loess deposit is a glacial till material which may be described as a brown-gray fine sandy clay silt with a trace of coarse sand. The glacial till extends to a depth of about 4.0 to 5.5 m below the ground surface at the site. Underlying the glacial till is an alluvial deposit which varies from a gray very fine sandy clay silt to a gray very fine sandy silt. A schematic diagram (10) showing the general soil profile of the site is contained in Appendix B. Bulk density measurements were performed at selected sites within the disposal area and control fields and are also presented in Appendix B. Lower bulk density measurements at the surface were a result of recent discing at the site before sampling (10).

No infiltration studies have been made at the site. However, plant operating personnel have noted that the infiltration rate has slowed over the past six years. Considerable ponding and surface runoff began to occur in 1977 during sludge applications (10).

Environmental Monitoring Data for the Land Disposal Operation

During the four-year period from January 1974 through December 1978, an annual average of 45.65 x 10^6 liters of aerobically digested sludge was applied on the 14.56 ha land disposal site. Sludge solids applications during this same period averaged 76.16 dry t/ha/yr (9).

The Sugar Creek plant aerobically digested sludge has been analyzed for heavy metal content. For the years 1975, 1976, and 1977 the sludge metal concentrations are shown in Table 10. For the period of 1975 through 1977, the average cadmium concentration was 16.3 μg/g. Using these average application and cadmium figures, the site has been receiving yearly cadmium applications of about 1.2 kg/ha (10).

For the four-year period from 1975 through 1978, about 157,177 kg of total nitrogen was applied to the entire Sugar Creek site or an average of 2,698 kg of total nitrogen per ha/yr. For the period March 1974 through June 1975, a total of 1,866 kg of phosphorus was applied to the entire site or an annual average of 128 kg/ha. For the four-year period 1975 through 1978, an annual average of 43.78 kg/ha of ammonia-nitrogen was applied to the site (10).

TABLE 10. SLUDGE METAL CONCENTRATION IN SUGAR CREEK PLANT SLUDGE FOR 1975, 1976 and 1977 (Dry Weight Basis) *

Year	Metal concentrations (μg/g)						
	Cd	Zn	Ni	Mn	Cr	Cu	Fe
1975	14	1,669	55	710	414	318	20,300
1976	20	844	35	844	521	417	18,233
1977	15	654	39	762	340	413	18,508

* Reprinted with permission to use.

Source: Alvey, Robert A. Effects of Aerobic Sludge Disposal on Land. Presented at the 1979 Annual Water Pollution Control Federation Conference in Houston, Texas, October 1979.

During the four-year period from January 1974 through December 1978, an annual average of 133,246 m^3 of rainfall fell on the disposal area making a total of 178,893 m^3 of liquid applied per year to the disposal area. In the same period, 129,233 m^3 of underdrainage per year was pumped back from the sludge application site to the treatment plant leaving approximately 49,588 m^3/yr of water unaccounted for. It is assumed that this amount was lost in evaporation, plant uptake and possible loss to groundwater (10).

The average BOD_5 and suspended solids levels and fecal coliform densities in the digested sludge over the four-year period of 1975 through 1978 were 2,730 mg/l, 24,840 mg/l and 822,000 cnt/100 ml, per year respectively. The pH of the sludge was 7.1 and the pH of the underdrainage water returned to the plant was 7.0 (10). Table 11 shows the average BOD and suspended solids concentrations and fecal coliform densities in drainage water from the Sugar Creek sludge application site for the period January 1974 through June 1975. The only apparent trend is a lower density of fecal coliform during the winter months (9).

For the period of March 1974 through June 1975, the total nitrogen, ammonia-nitrogen, nitrate-nitrogen and phosphorus content in the underdrainage water from the sludge application site is shown in Table 12. The underdrainage was relatively low in PO_4, NH_3-N, and total N levels with the monthly averages below 1 mg/l.

TABLE 11. UNDERDRAINAGE WATER CHARACTERISTICS--SUGAR CREEK PLANT*

Month	Year	Number of determinations	5-day BOD (mg/l)	SS (mg/l)	Fecal coliform (cnt/ 100 ml)
January	1974	--	--	--	--
February	1974	1	1.0	8.0	740
March	1974	2	0.5	21.5	1,200
April	1974	3	1.4	5.5	1,130
May	1974	1	1.9	4.9	850
June	1974	2	0.6	1.6	100
July	1974	2	0	3.5	750
August	1974	3	0.5	2.6	9,533
September	1974	3	0.3	4.3	5,280
October	1974	4	0.5	4.9	96
November	1974	3	0.3	9.0	11
December	1974	3	0.3	5.4	8
January	1975	5	0.4	4.9	25
February	1975	5	1.2	3.1	157
March	1975	8	1.2	1.6	93
April	1975	3	1.1	1.9	3
May	1975	2	3.0	5.9	67
June	1975	3	1.9	7.0	4
Total		53	16.1	95.6	20,047
Average		3	0.9	5.6	1,179
Median					100

* Used by permission of Water Pollution Control Federation.

Source: Andrew, R.C., and A.P. Troemper. Underflow from Sludge Irrigated Cropland. Journal Water Pollution Control Federation, 49:161-184, 1977.

TABLE 12. SUGAR CREEK PLANT UNDERDRAINAGE WATER NUTRIENT CONTENT*

Month	Year	Underdrainage water		
		PO_4 (mg/l)	TKN-N (mg/l)	NO_3 (mg/l)
January	1974	--	--	--
February	1974	--	--	--
March	1974	0.33	0	0.8
April	1974	0.67	0.9	1.8
May	1974	0.55	1.4	2.0
June	1974	0.42	1.0	0.7
July	1974	0.42	0.5	1.2
August	1974	0.34	0.4	5.8
October	1974	0.17	0.1	6.2
November	1974	0.23	1.6	14.7
December	1974	0.21	0	16.0
January	1975	0.24	0	45.9
February	1975	0.61	0	26
March	1975	0.49	0	21.7
April	1975	0.23	0	21.0
May	1975	1.01	0.7	18.4
June	1975	0.82	0	24.6
Monthly Average		0.45	0.4	13.5

* Reprinted with permission to use.

Source: Alvey, Robert A. Effects of Aerobic Sludge Disposal on Land. Presented at the 1979 Annual Water Pollution Control Federation Conference in Houston, Texas, October 1979.

Crops Grown--

In 1976 and 1977, corn was grown on the site. In 1976 the average corn yield was about 64.3 hl/ha, but in 1977, a corn borer problem reduced yields to 21.7 hl/ha (6). In 1978, grass was grown at the Sugar Creek site to produce sod for the local Springfield, Illinois landscaping market. However, the sod was not saleable because of the depressed housing market. The grass is dense and healthy with good coverage. The Springfield Sanitary District staff is satisfied with the existing grass cover.

Soil Analysis--

On July 17, 1975, the soil at the Sugar Creek sludge application site was analyzed for four metals and soil from an area where no sludge was applied. The soil was sampled at depths of 25.0 cm, 50.0 cm, and 76.0 cm. The results of these analyses are presented in Table 13 (9). No significant accumulations of any metal are evident.

TABLE 13. SOIL ANALYSIS - SUGAR CREEK SLUDGE APPLICATION SITE*

	25.0 cm soil depth		50.0 cm soil depth		76.0 cm soil depth	
Metal	Sludge metal concentration (mg/l)	Control metal concentration (mg/l)	Sludge metal concentration (mg/l)	Control metal concentration (mg/l)	Sludge metal concentration (mg/l)	Control metal concentration (mg/l)
Chromium	0.51	0.68	0.30	0.51	0.48	0.34
Lead	0.34	0.27	0.24	0.22	0.24	0.17
Cadmium	2.8	3.3	2.9	3.2	2.0	3.0
Nickel	2.9	3.3	2.3	1.8	1.9	2.7

* Used by permission of Water Pollution Control Federation.

Source: Andrew R.C., A.P. Troemper. Underflow from Sludge Irrigated Cropland. Journal Water Pollution Control Federation, 49:161-184, 1977.

Metal Level in Plants--

Table 14 shows the metal data for the analysis of corn grain grown on the Sugar Creek site in 1976 and 1977 (10). Sludge application has resulted in increased levels of metals in the grain compared to the controls. While the cadmium concentrations have increased, these concentrations were below 1.0 µg/g in both 1976 and 1977. As noted previously, no food chain crops have been grown on the site since 1977.

Public Acceptance

The Sugar Creek sludge disposal site is located in a remote area adjacent to the Springfield, Illinois Sanitary District Treatment Plant site. The site is bounded on two sides by limited access highways, on one side by a forest area owned by a railroad and the other side by private property owned by a local resident. The closest residence is about 610 m away. There are only three residences within 1.6 km of the site. Apparently there has been no local criticism of the sludge application site, because of the remoteness of the site and the sludge applied generates very little odor.

TABLE 14. HEAVY METAL CONTENT OF CORN GRAIN GROWN AT THE SUGAR CREEK SLUDGE APPLICATION SITE*

Metal (μg/g)	1976 Sludge amended	1976 Sludge control	1977 Sludge amended	1977 Sludge control
Zn	39.0	18.8	28.5	19.5
Cu	10.5	5.5	3.3	2.3
Pd	0	0	0	0
Cr	1.9	0.8	1.0	1.0
Ni	1.8	1.3	1.0	1.0
Cd	0.8	0.01	0.03	0.01
Fe	72.0	23.8	61.0	34.0

* Reprinted with permission to use.

Source: Alvey, Robert A. Effects of Aerobic Sludge Disposal on Land. Presented at the 1979 Annual Water Pollution Control Federation Conference in Houston, Texas, October 1979.

Costs

On September 14, 1971, bids were taken to construct the Sugar Creek sludge disposal site. Details of the low bid costs for the Sugar Creek site are shown in Table 15. Included in the total construction costs (1980 dollars) are: (a) the sludge pumping station; (b) the forced main and spray application system; (c) the underdrainage pipe; (d) miscellaneous (fencing and electrical work); and (e) land costs (11).

Operation of the sludge disposal area at the Sugar Creek site consists of the following steps. The operator positions the sprinklers in the sludge application area as desired, opens the necessary valves at the aerobic digester and starts up the comminutor and sludge pump. At the end of four hours, the operator turns off the pump and comminutor and closes the valve at the digester. The entire operation takes only one hour of operator time per week.

TABLE 15. SUGAR CREEK PLANT SLUDGE DISPOSAL SITE CAPITAL COSTS (1980 DOLLARS)****

Item	Total cost ($)	Annual cost ($)	Unit cost *($/t)
Pumping station	102,059.00	11,987.85**	10.80
Sludge distribution system	155,957.00	18,318.71**	16.50
Disposal area drainage	122,019.00	14,332.00**	12.91
Fencing and electrical work	42,203.00	4,957.00**	4.46
Land	69,513.00	6,951.00***	6.26
TOTAL	491,751.00	56,546.56	50.93

* 1,110 t of sludge applied per year to the site.
** 20-year life, 10 percent interest.
*** Infinite life, 10 percent interest.

**** Used by permission of Water Pollution Control Federation.

Source: Andrew, R.C., and A.P. Troemper. Underflow from Sludge Irrigated Cropland. Journal Water Pollution Control Federation, 49:161-184, 1977.

An analysis of operation and maintenance costs for the Sugar Creek site is shown in Table 16. All costs given are in 1980 dollars. Operation costs are about $3,500 per year. When a corn crop was grown in 1976 and 1977, return on crops for those years was $6,300 and $2,400, respectively (11).

Summary

The Springfield, Illinois Sanitary District has solved a sludge disposal problem by utilizing a dedicated land site for application of liquid, aerobically digested sludge from the Sugar Creek plant. The Sugar Creek site offers a permanent repository for sludge in contrast to the previous system which relied on nonpermanent private use of sludge as a fertilizer source.

The site utilizes spray application of liquid sludge during the entire year, since no sludge storage is provided. Sludge application to frozen ground is not a possible hazard to surface water, because all surface water is returned to the treatment plant. Sludge storage was considered undesirable due to problems in removing the stored sludge. Spray application presents no aesthetic problem due to the remoteness of the site and low odor potential of the aerobically digested sludge. The permanent mounted spray

TABLE 16. SUGAR CREEK PLANT SLUDGE DISPOSAL OPERATION AND MAINTENANCE COSTS (1980 DOLLARS)**

Cost item	Annual cost ($)	Unit cost *($/t)
Operator pay including fringe benefits	605.93	0.55
Power cost to apply sludge	656.10	0.59
Power cost of drainage pump at sludge farm	1,001.49	0.902
Repairs	1,181.70	1.06
Total	3,444.22	3.10/t

* 1,110 t of sludge applied per year to the site
** Reprinted with permission to use.

Source: Troemper, Paul A. Sludge Irrigation - An Economic Disposal Method. Presented at the 47th Annual Meeting of the Central States Water Pollution Control Association, St. Paul Minnesota, May 1974.

application system coupled with noncropping of the land requires relatively little operator time.

METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO HANOVER PARK LAND DISPOSAL OPERATION

Description of the Hanover Park Water Reclamation Plant and Sludge Disposal Operation

The Metropolitan Sanitary District of Greater Chicago (District) operates the Hanover Park Water Reclamation Plant. This plant has a dry weather flow capacity of 45,420 m^3/day and currently treats an average flow of 30,280 m^3/day. The treatment plant consists of circular primary settling tanks, a single stage activated sludge nitrification system, sand filters, and chlorination (12). Primary sludge, waste activated sludge, and sand filter washings are concentrated in an air flotation unit which feeds single stage heated complete mix anaerobic digesters. All treatment plant digested sludge is then either spread on the land directly or stored in an on-site lagoon during the winter season. Lagoon sludge can be pumped to adjacent land by means of submersible pumps, which are lowered from rafts floating on the lagoon surface.

In 1968, the District established a 2.83 ha experimental farm at its Hanover Park Water Reclamation Plant. The site was immediately adjacent to the Hanover Park Water Reclamation Plant and liquid anaerobically digested sludge from this plant was used in a gated pipe application system to fertilize corn grown at the site. The purpose of the farm was to gather information on the environmental impacts and feasibility of using liquid digested and lagooned sewage sludge for growing crops. The farm was designed so that the effects upon groundwater, soil and crops could be determined. Because all of the sludge generated at the Hanover Park plant could not be placed on the 2.83 ha farm, the excess sludge was either lagooned on site or transported to a nearby District plant for handling. In July 1979, a 50.18 ha farm was placed into operation immediately adjacent to the 2.83 ha experimental farm. (The total farm area is 83 ha, the 32.82 ha difference is needed for maneuvering equipment and for use as a buffer zone.) This 50.18 ha farm was designed to handle present and future sludge production from the Hanover plant. In 1981, the experimental farm operation was discontinued and it was added to the full-scale farm acreage.

The experimental farm had shown the feasibility of utilizing the sludge solids from the Hanover plant for fertilizing agricultural crops. The District believed that acquiring additional land adjacent to the experimental farm was justified by the results of the experimental farm operations. The data from the experimental farm were used to design the full-scale farm and apply for an operating permit from the IEPA.

The District decided to adopt the dedicated land application concept for its Hanover Park plant for the following reasons:

1. Dedicated land offered a permanent repository for the sludge generated at the Hanover Park plant.

2. Environmental monitoring at the Hanover Park experimental farm indicated no adverse impacts.

3. Local residents were not adverse to the operation of the experimental farm.

4. Based upon Hanover Park experimental farm sludge loading rates, about 83 ha of land was needed to handle the present and future Hanover Park plant sludge production, and this area of open land was available for purchase immediately adjacent to the Hanover Park plant.

5. Operation of the Hanover Park experimental farm indicated that relatively low amounts of operator time were required if gated pipe liquid sludge application was used.

Because the full-scale farm has been in operation for only two years and the experimental farm was operated for over 12 years, the monitoring data from the experimental farm was of more value in assessing the environmental impacts of the full-scale operation. The data from the experimental farm are directly applicable to the full-scale site, since the sludge, soil, climate, and underdrainage systems are identical for each site.

Description of the 2.83 Hectare Experimental Farm--

The original design of the experimental farm was a randomized block with five replications and three sludge loading rates equivalent to a depth of 0, 6, and 12 mm of liquid digested sewage sludge per week. Sludge was applied in furrows between rows of the growing corn. In order to grade the plots for furrow irrigation, the topsoil was first stripped, the subsoil graded to the desired slope and the topsoil replaced. The soil can be described as a poorly drained, distributed Drummer silty loam. The experimental plots had grades of 0.5, 1.5, and 2.5 percent. Figure 2 is a schematic of the experimental farm (13).

Four monitoring wells approximately six meters in depth were placed at the corners of the field plots for sampling groundwater. A single drain tile bisects the field plots draining south to north. The tile was overlain with gravel. All plots drain towards the center drain tile. All underdrainage and surface water from the experimental farm are returned to the influent to the Hanover Park plant. Sludge is applied at the high ends of the fields by gated irrigation pipe (13).

Description of the Full-Scale Farm--

The District owns 83 ha of open land immediately adjacent to and south of the Hanover plant. The entire site was graded to slopes of about one percent, and has 15 separately bermed application fields with a total application area of 50 ha for farming. The experimental plots are located immediately north of the 83 ha full-scale farm. Figure 3 shows the location of the seven existing monitoring wells on the site (13). Well number 2 was eliminated during construction for an access road. An underground force main conveys sludge to the site.

The fields have a tile drainage system for collecting infiltration and surface water runoff. The tile system consists of laterals spaced at 15.2 m intervals under the drainage collection areas. The areas underdrained by lateral drainage pipes are those which could be covered by ponded field runoff during a 100-year storm at the low ends of the fields. The drainage system has blind surface inlets to allow for rapid drainage of the ponded areas. Drainage can be diverted either to a nearby stream or returned to the Hanover plant. However, the IEPA Permit Number 1974-DB-218, requires all drainage to be returned to the treatment plant.

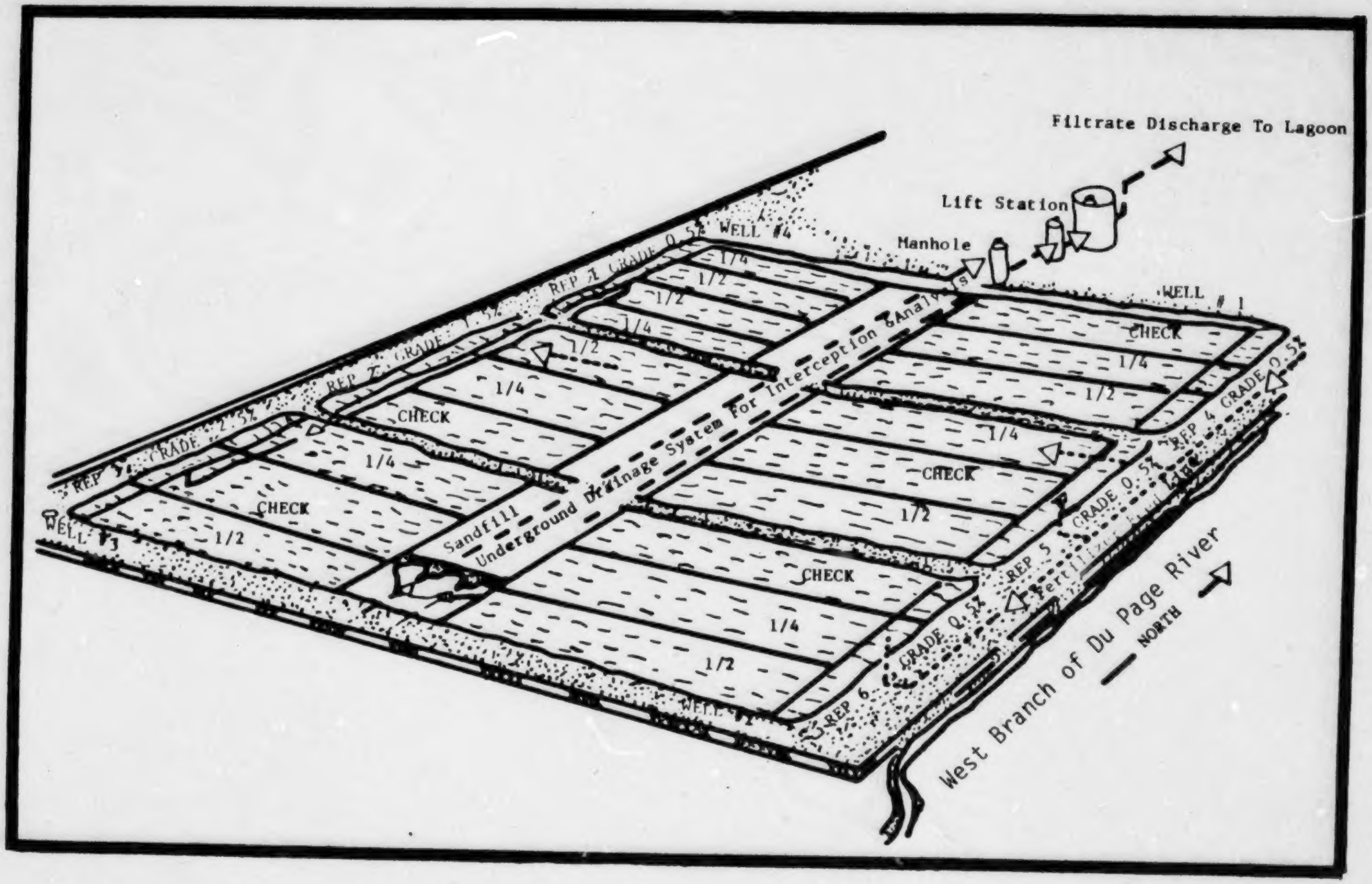
Filtrate Discharge To Lagoon
Lift Station
Manhole
WELL #4
WELL # 1
WELL #3
WELL #2
REP 1 GRADE 0.5%
REP 2 GRADE 1.5%
REP 3 GRADE 2.5%
REP 4 GRADE 0.5%
REP 5 GRADE 0.5%
REP 6 GRADE 0.5%
CHECK
1/4
1/2
Sandfill
Underground Drainage System For Interception & Analysis
Fertilizer
West Branch of Du Page River
NORTH

Figure 2. Liquid digested sewage sludge utilization on land, Chicago Hanover Park, Illinois Experimental farm site.

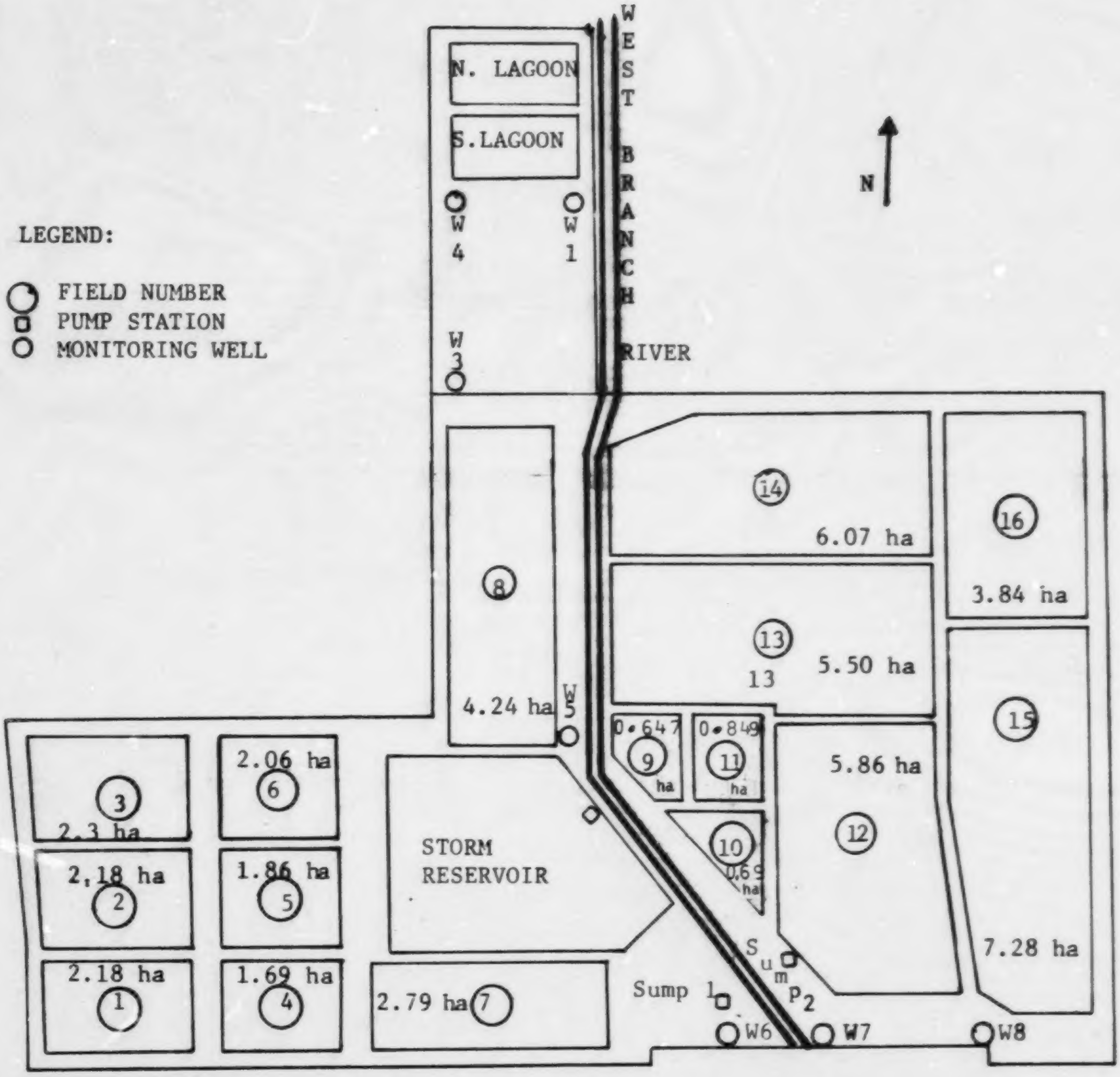
LEGEND:
FIELD NUMBER
PUMP STATION
MONITORING WELL
N. LAGOON
S. LAGOON
W 4
W 1
W 3
WEST BRANCH RIVER
N
6.07 ha
3.84 ha
5.50 ha
13
4.24 ha
W 5
0.647 ha
0.849 ha
5.86 ha
2.06 ha
2.3 ha
2.18 ha
1.86 ha
STORM RESERVOIR
0.69 ha
7.28 ha
2.18 ha
1.69 ha
2.79 ha
Sump 1
Sump 2
W6
W7
W8
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

Figure 3. Farm fields at the sludge application site, Chicago Hanover Park experimental farm.

Geology of the Site--

The sludge application fields are located on Valparaiso Glacial Drift and have an uneven topography with knobs, depressions and wet areas. Slopes before grading varied from less than one percent to approximately ten percent. The glacial till is generally gray to brownish gray clay with a few small areas where the till is yellowish gray, silty and gravelly. The natural drainage of the site is rather poor. Crops of corn and soybean were successfully grown on the full-scale farm before it was purchased by the District (14).

The surface soil is usually black silty clay loam or a very dark grayish brown silt loam ranging in depth from 15.24 cm to 61 cm. The surface soil is high in organic matter and has a crumbly texture and moderate permeability. The subsoil is a brown silty clay or a gray silty clay loam with a moderately low permeability and a few small stones. Stiff silty clays are usually found below 4.6 m. The organic matter content (as organic carbon) in the surface soils is greater than five percent which is high compared to the 0.8 to 0.9 of 1 percent found in the subsoil (14). The drift is 100 to 200 feet thick under the site. Since the drift is predominantly low permeability glacial till, it will protect the underlying dolomite aquifer (14).

Environmental Monitoring Data for the Land Disposal Operation

Sludge Application Quantities to the Full-Scale Farm--

Application to the full-scale farm began in July 1979. In 1979, application quantities to individual fields ranged from 0 to 11.62 t/ha of solids. In 1980, applications ranged from 2.02 to 32.5 t/ha (15).

The full-scale farm is designed to receive approximately 34 to 45 t/ha/yr of sludge; which is the loading rate applied on the experimental farm. For example, for the eight-year period 1968 through 1975, the maximum sludge applied to the plots on the experimental farm was about 31.4 t/ha/yr. For the same period (1968 to 1975), 1.74 kg/ha/yr of cadmium was applied in the highest rate of sludge in application to the experimental farm. Total nitrogen and ammonia-nitrogen applications for the eight-year period were 1,480 and 863 kg/ha/yr respectively for the experimental farm. These rates of solids, cadmium and nitrogen applications are typical of what can be expected in the future for the full-scale farm (15).

Metal Levels in Sludge Applied to the Hanover Park Experimental Farm

Table 17 contains average levels of various constituents in the Hanover Park sludge applied to the experimental farm for the years 1970, 1973, 1976, and 1979 (15). The sludge had a total nitrogen content of 5 to 7 percent, a phosphorus content of 1.5 to 2 percent and a cadmium content ranging from 10 to 300 μg/g.

TABLE 17. AVERAGE ANNUAL CHEMICAL CONTENT OF THE SLUDGE APPLIED TO THE HANOVER PARK EXPERIMENTAL FARM FOR 1970, 1973, 1976 and 1979 (Dry Weight Basis)

Parameter	Units	Year			
		1970	1973	1976	1979
pH*	unit	6.8-8.4	7.1-7.6	6.9-7.6	NA
TS*	%	4.41	3.4	2.03	2.1
TVS	%	40.8	46.6	61.1	61.6
Total P	%	1.60	1.42	2.02	1.43
Total-N	%	5.39	4.61	7.84	5.77
NH_3-N	%	4.04	2.44	3.59	1.82
Cl	μg/g	1,200	7,700	1,840	NA
Alkalinity	μg/g	18,000	63,700	150,000	NA
Fe	μg/g	33,000	17,200	12,700	11,700
Zn	μg/g	690	720	700	900
Cu	μg/g	540	700	1,100	1,700
Ni	μg/g	490	80	100	200
K	μg/g	--	2,600	5,000	2,700
Na	μg/g	--	5,000	16,000	8,000
Mg	%	--	1.22	0.87	0.81
Ca	%	--	2.89	2.48	2.93
Pb	μg/g	510	170	200	200
Cr	μg/g	150	220	600	700
Cd	μg/g	120	40	300	10

* Not on dry weight basis.
Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

Again, because of the comparatively low sludge applications to the full-scale farm, data on soil constituents from the experimental farm are assumed representative of the full-scale farm operation. Table 18 presents soil data for two sludge application rates and a site not receiving sludge for the years 1970, 1973, 1975, and 1979 (15). Sludge application has increased the nutrient and metal content of the soil.

Groundwater Analysis

As in previous sections, environmental effects are discussed using data from the experimental farm.

Table 19 shows data on average groundwater quality of the four monitoring wells (Figure 2) which surround the experimental farm for the years 1970, 1975, and 1980 (15). There has been virtually no change in the groundwater quality since sludge application began at the 2.83 ha experimental farm in 1968.

TABLE 18. CHEMICAL AND PHYSICAL PROPERTIES OF SOIL AT THE HANOVER PARK EXPERIMENTAL FARM FOR 1970, 1973, 1975 AND 1979

Parameter* (mg/kg)	1970			1973			1975			1979		
	Total sludge applied			Total sludge applied			Total sludge applied			Total sludge applied		
	0 (t/ha)	34 (t/ha)	56 (t/ha)	0 (t/ha)	83 (t/ha)	139 (t/ha)	0 (t/ha)	117 (t/ha)	204 (t/ha)	0 (t/ha)	139 (t/ha)	231 (t/ha)
pH**	7.9	7.7	7.7	7.3	7.1	7.1	3.8	7.5	7.6	7.1	7.2	7.2
CEC***	33.4	34.0	32.2	33.9	33.7	33.3	31.4	34.5	32.3	31.2	33.5	32.3
C-organic****	3.08	3.21	3.15	2.61	3.37	3.33	2.66	3.35	3.01	1.80	2.65	2.31
P,-available	+	+	+	9.8	51.5	79.8	31.3	102.9	113.9	13.9	202	204
K	138	158	153	126	149	126	106	122	117	146	174	144
Na	95	131	117	25	30	44	22	84	78	68	86	99
Ca	5,440	5,660	5,530	5,140	6,300	5,650	4,300	4,680	4,590	4,862	4,453	4,726
Mg	1,520	1,600	1,600	1,600	1,700	1,690	1,060	1,100	1,060	1,298	1,274	1,232
Fe	813	827	835	301	339	346	247	409	412	396	515	618
Mn	253	281	290	198	200	195	211	222	235	221	256	260
Zn	30.5	39.0	37.5	24.4	23.4	27.6	22.9	50.0	51.7	12.8	50.7	53.4
Cd	0.7	0.7	0.5	0.68	.58	0.61	0.39	0.49	0.50	0.5	2.7	2.4
Cu	18.3	66.6	33.8	6.72	13.3	15.8	9.3	23.2	30.2	8.6	44	50
Cr	1.7	2.3	5.2	0.93	1.26	1.47	0.42	1.02	1.46	1.1	4.2	4.1
Ni	11.3	10.9	10.9	8.60	9.11	8.93	6.78	8.15	7.39	6.2	7.3	8.1
Pb	16.2	11.8	13.3	8.25	9.21	9.68	9.1	12.0	13.9	7.8	12.4	17.0

* All units in mg/kg, except where indicated otherwise.
** pH units.
*** Units - meq/100g.
**** Units - %.
+ Not analyzed.
Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 19. HANOVER PARK EXPERIMENTAL FARM AVERAGE ANNUAL WELL WATER ANALYSIS FOR 1970, 1975 and 1980

Constituent* (mg/l)	Year		
	1970	1975	1980
Total P	0.2	0.18	0.3
Cl	9	22.5	22
SO_4	167	18.7	172
TKN	0.5	0.82	0.7
$N\text{-}NH_3$	0.4	0.35	0.4
$NO_2+NO_3\text{-}N$	0.34	0.20	0.5
Alkalinity as $CaCO_3$	323	256	287
Electrical conductivity**	971	634	868
K	1	1.25	2
Na	11	11.2	10
Ca	92	85.8	65
Mg	63	62.5	66
Zn	0.5	0.22	0.1
Cd	0.01	0	0.00
Cu	0.06	0.16	0.01
Cr	0.00	0	0.00
Ni	0.06	0	0.00
Mn	0.21	0.28	0.29
Pb	0.04	0.04	0.02
Fe	18.3	222	16.0
Fecal coliform***	11.0	1.0	2

* All units are mg/l, except where indicated otherwise.

** Units - µmhos/cm

*** Units - cnt/100 ml

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

Quality of Underdrainage Water

The full-scale farm has not been in operation long enough to collect adequate data on underdrainage water. Therefore, data from the experimental farm will be used as illustrative of the quality of underdrainage water expected from the full-scale farm. As noted previously, annual cadmium and total nitrogen loadings have averaged approximately 1.74 and 1,480 kg/ha. Zn, Cu, Ni and Pb loadings have averaged 22.6, 22.0, 2.51 and 5.34 kg/ha/yr, respectively (15).

Table 20 (15) depicts average underdrainage water quality for the years 1969, 1973, 1976 and 1980 for the entire experimental farm. As can be seen, there has been a steady rise in NO_2+NO_3-N content of the underdrainage water, but the other constituents present remained fairly constant over the period. There was no adverse impact of this water upon the quality of nearby surface water since all the drainage was returned to the Hanover Park plant.

Crops Grown on the Hanover Park Site

The experimental farm has always grown corn. The full-scale farm has been used to grow both grass (oats and fescue) and corn. In 1979 grass was planted in all fields and no grass was removed in that year. In 1980 corn was planted in 9 of the 16 fields and the crop was sold. The grass grown in 1980 on the other fields was not harvested. Eventually, corn will be planted on all of the full-scale farm.

Corn Yields at the Hanover Park Experimental Farm

Because of the low sludge applications to the Hanover Park full-scale farm, corn yields for the farm are not indicative of what would be expected when larger amounts of sludge are applied. Table 21 presents data on the corn yields from the experimental farm for the years 1970, 1975, and 1980 (15) Yields have been variable, and as with any farming operation, the yields are dependent upon climate and other factors. However, yields have been higher with sludge application as compared to the control fields which receive inorganic fertilizer.

Plant Metal Uptake

Table 22 presents data on average metal levels in the corn grain grown at the Hanover Park experimental farm for the years 1973, 1975, and 1979 (15). In general, there has been little increase in corn grain metal levels.

TABLE 20. AVERAGE ANNUAL CHEMICAL AND FECAL COLIFORM CONTENT OF THE TILE UNDERDRAINAGE AT THE HANOVER PARK EXPERIMENTAL FARM (2.83 HECTARES)

Constituent* (mg/l)	Year 1969	1973	1976	1980
pH**	7.6	7.6	7.6	7.6
Total P	0.22	3.12	0.69	1.6
Cl^-	40	81	96	96
$SO_4^=$	156	36	132	173
Total-N	1.17	15	4.8	8.4
$N\text{-}NH_3$	0.68	11.4	3.8	7.3
$N\text{-}NO_2+NO_3$	5.46	21.8	17.3	50.8
Alkalinity	346	388	451	424
Conductivity***	1,048	1,318	1,070	1,628
Na	18.4	35.7	48	45
Ca	136	133	158	151
Mg	51	65	72	70
Zn	0.03	0	0	0
Cd	0	0	0	0
Cu	0.02	0.06	0.03	0.01
Cr	0	0.01	0	0
Ni	0	0	0	0
Pb	0	0.07	0.03	0.03
Fe	5.7	2.45	3.1	0.61
Fecal coliform****	25	41	11	751

* All units are mg/l, except where otherwise indicated.
** Units - pH units.
*** Units - μmhos/cm.
**** Units - cnt/100 ml.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 21. CORN YIELDS FOR THE HANOVER PARK EXPERIMENTAL FARM*

Parameter (hl/ha)	Total sludge applied by year (t/ha)								
	1970			1975			1980		
	0	33.6	56	0	190	246	0	291	435
Corn yields	21	40	40.8	43	84	72	24	70	56

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

Regulatory Constraints at the Park Site

The Hanover Park full-scale farm is currently operating with an IEPA permit. This permit (#1974-DB-218) has several special conditions which are listed below.

1. All runoff from the tile drains must be returned to the Hanover Park treatment plant for treatment prior to discharge to the east branch of the DuPage River.
2. The District "...shall restrict as necessary its procedures of land application to gated irrigation pipe (ridge and furrow) to adequately control odor emissions so that land application of the sludges does not cause or become the source of air pollution emissions."

The full-scale farm is operated so that all of its surface/subsurface drainage is returned to the treatment plant. In addition, the full-scale farm uses gated irrigation pipe for applying sludge similar to the experimental farm.

The full-scale farm operation must also comply with the U.S. EPA Criteria (1). The District intends to comply with the criteria by selling the corn grown only for animal feed. In this way, the District can apply sludge without restriction on the amount of sludge cadmium applied to the fields.

TABLE 22. METALS CONCENTRATIONS OF CORN GRAIN GROWN AT THE HANOVER PARK EXPERIMENTAL CORN PLOTS

Year	Total sludge applied (t/ha)	Zn (μg/g)	Cd (μg/g)	Cu (μg/g)	Cr (μg/g)	Fe (μg/g)	Ni (μg/g)	Pb (μg/g)	K (μg/g)	Na (μg/g)	Ca (μg/g)	Mg (μg/g)	Mn (μg/g)
1973													
	0	25.0	0.5	1.74	0.77	39.2	0.5	0.81	3,030	26.2	57.9	1,330	5.07
	117	25.8	0.5	2.01	0.76	34.4	0.5	0.83	3,600	27.2	70.6	1,340	5.51
	177	23.8	0.5	1.70	0.71	36.9	0.5	0.79	3,158	32.1	55.0	1,240	5.65
1975													
	0	18.2	0.067	1.81	0.076	23.6	0.63	0.54	3,260	9.71	61.4	1,070	5.70
	190	25.8	0.091	2.32	0.058	29.8	0.43	0.53	3,490	2.78	57.8	1,140	6.52
	246	25.8	0.096	2.29	0.067	30.3	0.48	0.51	3,380	3.39	54.2	1,160	6.52
1979													
	0	18.0	0.28	1.44	0.11	19.5	0.43	0.31	3,612	15.0	47	1,263	5.14
	175	19.7	0.31	2.13	0.14	20.0	0.64	0.04	3,356	8.8	46	1,484	4.77
	302	21.4	0.14	1.18	0.10	20.6	0.44	0.04	3,452	7.1	47	1,494	4.66

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

Social and Aesthetic Issues

Sludge applications began on the experimental farm in 1968. The experimental farm was located within 6.1 m of the backfences of single family suburban residences. Yet, District personnel stated that the public acceptance of the experimental farm was good, since few complaints from local residents were received regarding the farm operation. Gated pipe sludge application gave the operation low visibility and the local residents were familiar with the previous private farming operations connected with corn production.

The full-scale farm began operation in July 1979. This farming operation maintained the previous use of the land by growing corn and soybeans. However, sludge application was added to the overall operation. The full-scale farm is bounded on the west by a 2-lane highway, and on the south by a railroad right-of-way. Except for the adjacent sludge lagoons on the north, the farm is surrounded by a grade school, and single family suburban residences, some of which have backfences adjoining the farm. District personnel have received no public complaints regarding the operation of the full-scale farm. The personnel attribute the lack of complaints to the careful operation of the experimental farm since 1968, the similarity of the farming operation previously done, and no nuisance conditions such as odors. The sludge used is well stabilized and thus low in odor potential.

Costs

In 1975, a contract was awarded for the construction of the large-scale farm. Details of the construction costs are shown in Table 23 (15). All costs are in 1980 dollars.

Although the large-scale farm has yet to receive its annual design sludge loading rate, maintenance and operation costs for 1980 are relatively indicative of what can be expected when the design sludge applications of 34 to 45 t/ha/yr are reached. In 1980, except for field No. 11, the site received sludge applications of 2.01 to 32.5 t/ha/yr. All fields were planted with corn or hay crops (15).

The 1980 maintenance and operations costs are given in Table 24. Total 1980 costs were $78,000 (15). Table 25 gives the unit costs for the full-scale farm. The full-scale farm should produce corn yields based upon data from the experimental farm of about 70 hl/ha. The farm should produce about 3,148 hl of corn. At the 1980 corn price of $9.40 per hl (16), the annual return should be $32,472 or $14.55/t of sludge applied. Total unit costs for the Hanover Park full-scale farm are $226/t.

TABLE 23. CONSTRUCTION COSTS FOR FULL-SCALE 50-HECTARES HANOVER PARK FARM (1980 DOLLARS)

Cost item	Cost ($)
Site grading	552,613
Subsurface drains	487,945
Culverts and services	74,955
Pressure pipeline	357,141
Gated irrigation pipe	32,334
Fence	279,246
Drainage pumps	374,489
General electrical work	73,486
Monitoring wells	23,516
TOTAL	2,255,725

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 24. MAINTENANCE AND OPERATIONS COSTS FOR THE FULL-SCALE HANOVER PARK FARM (1980 DOLLARS)

Cost item	Cost ($)
Labor (application of sludge)	28,000
Overhead	19,000
Labor (maintenance)	12,000
Overhead	8,400
Energy (electrical)	6,000
Farming (planting and harvesting) by contractor	4,000
TOTAL	78,000

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 25. UNIT COSTS FOR FULL-SCALE 50-HECTARES HANOVER PARK FARM (1980 DOLLARS)

Cost item	Annual cost ($)	Unit costs ($/t)*
Construction **	264,957	118.70
Monitoring	8,118	3.63
Application costs	78,000	34.94
Land costs ***	153,400	68.72
Subtotal	504,475	225.99
Return on crops****	(32,472)	(14.55)
TOTAL	472,003	211.44

* Based upon 2,232 t/year (50.18 ha receiving 44.5 t/ha of sludge)
** 10 percent, 20-year life
*** 10 percent, infinite life
**** Estimate, 3.148 hl of corn @ $9.40/hl
( ) Benefit on revenue

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

The costs for the Hanover Park operation are influenced greatly by the high costs for land grading to allow for the use of the gated irrigation pipe and the high cost of land in suburban Chicago. In addition, the cost of labor in the Chicago area is relatively high when compared to nationwide average labor costs for similar tasks.

SECTION 5

DEDICATED LAND DISPOSAL TYPE III SITES

INTRODUCTION

The Type III sites selected for data collection and analysis were the Fulton County land disposal operation owned and operated by the Metropolitan Sanitary District of Greater Chicago, and the Sacramento County, California land disposal operation owned and operated by the Sacramento County Sanitation District. The Fulton County site has been in operation since 1972 and the Sacramento County site was put into operation in 1981, but was not at full-scale operation when this study was made.

Both sites meet the requirements of Type III dedicated land disposal operations as given in this report and represent the situation of applying sludge to land at rates that greatly exceed the crop nitrogen requirements and the U.S. EPA cadmium restrictions (1). Crops are grown on the Fulton County site, but no crops are grown on the Sacramento County Site.

APPLICABLE STATE GUIDELINES

Illinois State Guidelines

The Illinois Environmental Protection Agency (IEPA) does not have uniform regulations or guidelines for sludge to land disposal operations in the state. Each operation is permitted individually and the requirements can range from none to what the IEPA considers necessary. The Fulton County site is operating on an IEPA permit, number 1981-SA-1972, that specifies 18 special conditions. These conditions specify: (1) the manner in which the sludge disposal operation is to be conducted; (2) site conditions; (3) the monitoring requirements; and (4) runoff water quality.

California State Guidelines

State and regional boards have primary responsibility for the control of water quality. The California Regional Water Quality Control Board, Central Valley Region (Regional Board) regulates surface and groundwater effects of any sludge handling and disposal programs implemented by the Sacramento Regional County Sanitation District. Regional Board rules and regulations indicate how sludge is to be handled.

The Regional Board will classify the sludge and the waste disposal sites. There can be no direct runoff from any sludge disposal site and groundwater must be protected. Nuisance conditions must be minimized. The State Solid Waste Management Board can regulate sludge handling and disposal. The State Department of Health can issue regulations on handling and application of sewage sludge to land and use of toxic waste as a soil amendment or fertilizer. Sacramento County controls land use through the County General Plan and the county's land use ordinances.

In California, major regulatory control of sewage sludge disposal can be exerted by the Regional Water Quality Control Board, State Department of Health and the County Department of Community Health. The SRCSD operation has received Regional Board approval.

METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO FULTON COUNTY SLUDGE DISPOSAL OPERATION

Description of the District's Wastewater Treatment Operation and Fulton County Sludge Disposal Operation

Description of the District's Treatment Systems--

The District owns and operates seven wastewater treatment plants. The West-Southwest (WSW), Calumet and North Side plants are secondary treatment works, while Hanover Park, Lemont, John E. Egan and O'Hare are tertiary treatment plants. The anaerobically stabilized sludge produced by the WSW and North Side facilities is shipped to Fulton County for land reclamation. The North Side facility has no sludge stabilization, utilization or disposal systems. After gravity thickening, North Side sludge is pumped to the WSW facility via pipeline for processing.

The WSW plant consists of the West Side Treatment Works, which is an Imhoff facility, and the Southwest Side Treatment Works, an activated sludge facility. The West Side Treatment Works consist of a grit chamber and screen house, skimming tanks, Imhoff tanks for sewage treatment and sludge stabilization, and sand drying beds for sludge dewatering of Imhoff sludge. Digested Imhoff sludge is dried on sand beds to about 25 percent solids and this sludge is scraped from the beds and hauled to a storage area 4.83 km west of the plant for further drying. The Southwest Treatment Works include aerated grit chambers, grit dewatering building, preliminary settling tanks, aeration tanks and final settling tanks. Heat drying and heated (35°C) high rate anaerobic digestion are the two sludge processes used at the Southwest Treatment Works.

By late 1960, the District was confronted with a serious problem of managing the solids that were removed from its West-Southwest Sewage Treatment Works (WSW). Historically, solids were either stored in lagoons in a liquid form, heat dried and sold as fertilizer, or air dried and stored in a landfill site. Space for lagooning and landfilling was running out (17).

In searching for a solution to its solids problems, the District was looking for a process whereby the solids could be utilized for some beneficial use; environmental problems could be minimized; and the solids disposal problem would be solved into perpetuity.

In 1967, the District decided to adopt a program of applying the stabilized sludge solids to land for use as an agricultural fertilizer. For several years, however, the District was unable to implement this program. Attempts at land acquisition within the Chicago and northern Illinois areas failed, because of a lack of public acceptance. By 1970, the District was faced with a very serious problem of what to do with the solids from the WSW plant, because of the inability to build additional lagoons and find landfill sites within its boundaries (17). In late 1970, the District purchased 2,895 ha of land in Fulton County, Illinois. Fulton County is a predominantly rural county of approximately 207,200 ha located in West Central Illinois on the west bank of the Illinois River approximately 289.6 km southwest of the District (17). The intention of the District was to develop a large-scale agricultural operation at the Fulton County site utilizing the District's sludge as the source of fertilizer. Because the land was owned by the District, the operation could be controlled and a site for utilization of the District sludge would be insured for a reasonable length of time.

Description of the Fulton County Land Disposal Site--

Currently the District owns about 6,283.9 ha of land in Fulton County. The land at Fulton County had previously been strip mined, and much of it was being used for livestock pasture prior to the District's operation. The original plan was to grade the land to control runoff, increase the humus content in the soil by adding large additions of organic matter via the digested sludge, and thus restore the land to full agricultural productivity (13).

Waste activated sludge and a small percentage of primary sludge is digested in heated (35°C) high rate digesters for 14 to 15 days at the District's WSW plant. The solids from the high rate digesters, and a portion of the solids that are stored in large holding basins (lagoons) near the WSW plant during warm weather are pumped to barges for transportation to Fulton County, approximately 322 km (by water) down the Illinois River. The barges are docked at Liverpool, Illinois, and the solids are pumped 17 km through a pipeline to three holding basins at the District's land utilization site (18).

Sludge was applied with traveling sprinklers from 1972 to 1975. By 1977, this method was replaced by soil incorporation with heavy duty, offset disks. Incorporation has several distinct advantages over traveling sprinklers. The incorporation device can apply a greater amount of sludge per application, because the sludge is mixed into the soil at the time of application. Also, the reduced visibility, in contrast to spray application, is an important aesthetic consideration. Incorporation devices can apply sludge to the perimeter of fields while such application is often spotty for spray application due to the difficulty of controlling the path of the spray under varying wind conditions (18). Figure 4 shows a typical application field. Application fields are situated on both nonmined (place land) and mine-spoil areas. Each field receiving sludge is bermed and drains to a field runoff retention basin. Each retention basin is designed to capture a storm event equaling the regional 100-year storm (15.5 cm). Runoff water is released only after it meets the State of Illinois permit standards (TSS 99 mg/l, BOD_5 33 mg/l and fecal coliform 494 cnt/100 ml) (19).

Site Geology--

The reclamation site is situated on Quaternary and Pennsylvania geologic formations. A geologic profile of areas based on well-boring data shows that the original geologic formations were approximately 0 to 12 m unconsolidated Illinois glacial deposits, loess (wind deposited soil) and alluvium, and 12 to 106 m of Pennsylvania formation consisting mainly of Canton shale with thin sandstone, limestone and coal beds.

Site profiles made on the mine spoil areas indicate subsurface compositions distinctly different from those of nonmined areas. In the strip mining operation, which took place in this area 12 to 20 years ago, the number 5 Springfield coal seam was exposed by removing all of the overburden material. In the process, the overburden from a new cut was returned to the previous cut where the coal seam had been mined. The returned overburden, however, consisted of a mixture of the previous strata with localized variability of soil types. Site soils are calcareous and poorly drained with textures ranging from loam to silty clay. A schematic diagram of the geology of the site is shown in Figure 9 in Appendix C (20).

The water table of the mine spoil areas is divided into discontinuous units. Visual observation of surface water areas at the Fulton County land reclamation site shows many instances where surface water bodies are at completely different elevations although they may be no more than 30 to 60 m apart, indicating little lateral groundwater movement (20).

Environmental Monitoring Data for the Land Disposal Operation

Sludge Application Quantities--

Sludge applied to the Fulton County agricultural fields since 1971 is typified by the 1979 data, Table 26 (18). One metric ton of sludge contains 40 kg of total nitrogen of which 16.8 kg is ammonia nitrogen making this sludge an excellent source of nitrogen. The sludge is well stabilized after high rate digestion and lagooning, and has a mean volatile solids content of 46.5 percent.

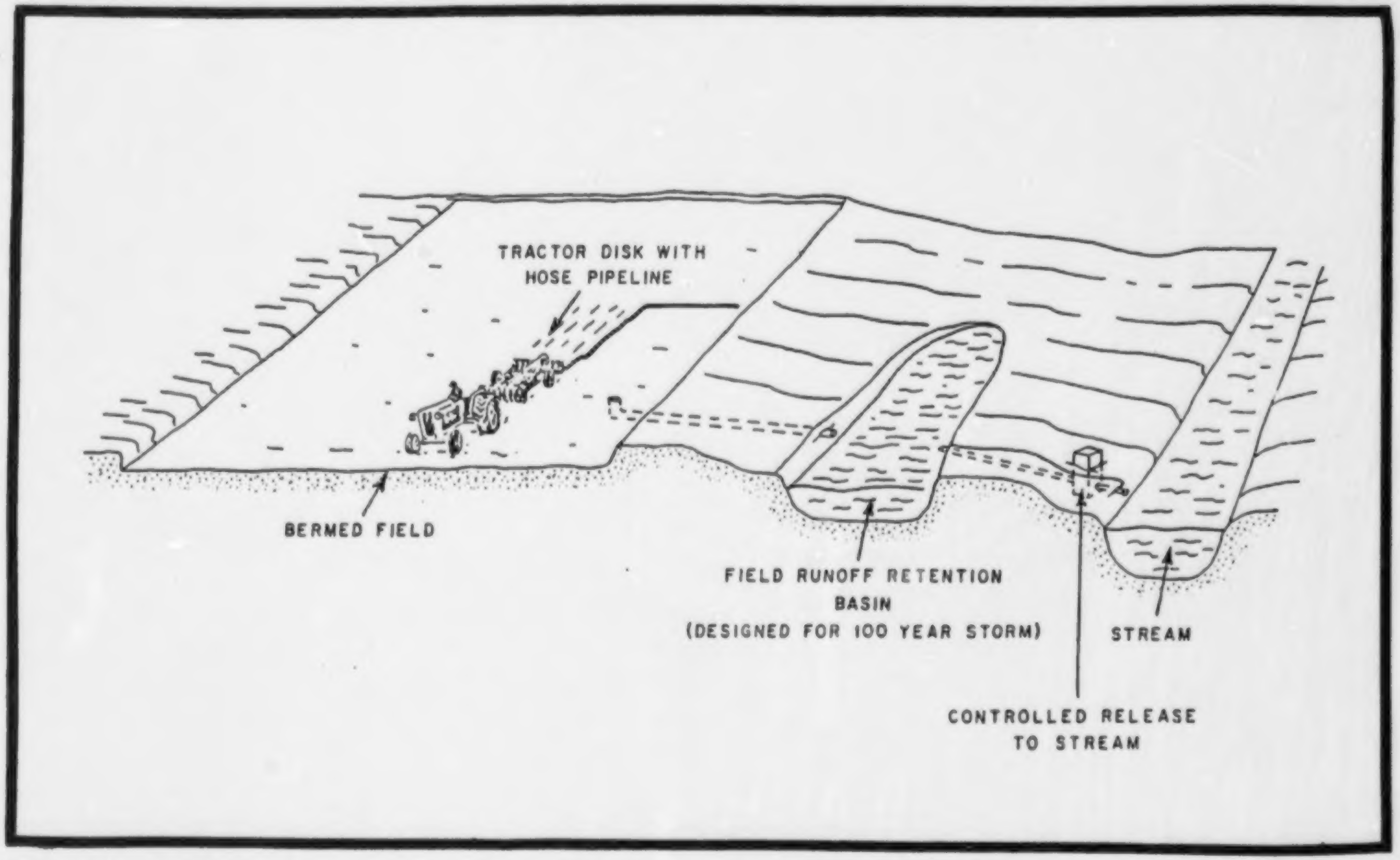
TRACTOR DISK WITH HOSE PIPELINE
BERMED FIELD
FIELD RUNOFF RETENTION BASIN (DESIGNED FOR 100 YEAR STORM)
STREAM
CONTROLLED RELEASE TO STREAM

Figure 4. Typical field design with runoff water capture system, Fulton County, Illinois. Courtesy of Metropolitan Sanitary District of Greater Chicago.

TABLE 26. RANGE OF THE PRINCIPAL CONSTITUENTS IN THE DIGESTED SLUDGE APPLIED TO FULTON COUNTY FIELDS FROM MAY 6 TO OCTOBER 21, 1979 (++)

Constituents	Minimum *(mg/l)	Maximum *(mg/l)	Mean *(kg/t)
pH **	7.0	7.9	--
E.C., µmhos/cm***	3,200	6,800	--
Total solids +	3.84	6.04	1,000
Total volatile + solids	42.4	51.4	46.5
Total P	1,212	2,060	30
N-Kjeldahl	1,026	2,435	40
N-NH_3	632	1,072	16.8
Alk as $CaCO_3$	2,250	5,300	64
Cl	176	960	7.01
Fe	1,561	4,790	46.4
Zn	131	226	3.61
Cu	63.0	181	1.77
Ni	13	43	0.46
Mn	12.2	29	0.42
K	40	250	3.1
Na	40	110	1.75
Mg	370	720	10.4
Ca	970	2,600	28.4
Pb	15.0	56.9	0.76
Cr	120	386	4.13
Cd	10.8	19.3	0.28
Al	410	830	12.3
Hg	0.049	0.368	0.0041

Source: Peterson, J. R., C. Lue-Hing, J. G. Gschwind, R. I. Pietz and D. R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982. 326 pp.

* Units as given, except where noted otherwise.

** Units - pH units.

*** Units - µmhos/cm (conductance)

+ Units - %

(++) Used by permission of The Pennsylvania State University Press.

The annual and cumulative sewage sludge applications through 1979 to selected Fulton County fields are shown in Table 27 (18).

Soil Analysis--

The metal and organic carbon concentration in mined lands and lands undisturbed at the Fulton County site that received sludge applications are given in Table 28 (15). For comparison purposes, data for land sites which have received no sludge are also shown in Table 28. Sludge application has increased the metal content in the soil.

Nutrient Additions from Sludge Application--

Sludge solids applications to the Fulton County site have not been constant because of differences in the solids content of the sludge and differences in weather conditions which affect sludge application. Table 29 shows data for field numbers 23, 19 and 15. These fields represent the range of sludge applications for the Fulton County site. Field number 23 represents a field receiving relatively low amounts of sludge, and field number 19 represents a field receiving medium sludge amounts. Sludge applications to field number 15, which has received high amounts of sludge, have averaged nearly 82.94 t/ha/yr, total nitrogen applications 3,869 kg/ha, NH_3-N averaged 1,707 kg/ha, and phosphorus averaged 2,539 kg/ha (15).

Air Monitoring--

The District has been collecting ambient air ammonia samples downwind of the Fulton County holding basins since August of 1973. Appendix C contains the monthly mean and range of ambient air ammonia levels from August of 1973 through September of 1980 (15). During the 8-year sampling period, the monthly mean air ammonia concentration varied from 0.05 to 3.82 μg/g (volume basis) and the daily air ammonia levels varied from 0 to 8.54 μg/g. The IEPA specified that air ammonia levels should not exceed 24.0 μg/g. This level has never been exceeded at the Fulton County site.

Groundwater--

Twenty-five groundwater monitoring wells are sampled on a monthly basis for 24 physical, chemical and biological parameters. The monitoring wells are drilled to the shale layer underlying the number 5 coal seam and are typically 10.7 to 21.3 m below the surface.

TABLE 27. ANNUAL AND TOTAL SLUDGE DRY MATTER APPLICATION FOR SELECTED FIELDS AT THE FULTON COUNTY, ILLINOIS SITE*

Field type	Field number+	Applied sewage sludge (t/ha) 1972	1973	1974	1975	1976	1977	1978	1979	Total applied sludge
Mine spoil										
	1	0		0	43	65	120	0	116	344
	2	0	0	54	41	129	83	36	107	450
	3	10	3.4	55	23	83	0	83	14	271
	5	0	1.8	52	90	81	0	53	75	353
	7	0	1.3	48	50	13	64	59	0	235
	25	0	0	22	65	0	112	85	27	311
	26	0	0	61	28	98	108	88	17	400
	28	0	0	38	82	95	0	79	135	429
	30	0	0	45	43	101	126	23	115	453
	34	0	0	0	71	18	64	58	59	270
	Weighted average	10	2.2	46	56	82	93	68	69	352
Non-Mined										
	10	0	0	58	45	67	69	60	63	362
	19	0	3.6	37	20	50	41	37	74	263
	20	0	0	52	20	39	32	58	69	270
	21	0	5.4	61	27	32	62	60	66	313
	22	4.0	2.0	14	28	48	17	59	64	236
	23	0	0	0	39	17	55	56	66	233
	31	0	0	19	94	14	60	68	78	333
	35	0	0	0	25	51	39	58	61	234
	37	0	0	16	65	16	53	57	80	287
	40	0	0	0	0	55	29	60	73	217
	Weighted average	4.0	3.7	37	40	39	46	57	69	275

+ Weighted average takes into account only those fields receiving sewage sludge for the year in the table.

* Used by permission of The Pennsylvania State University Press.

Source: Peterson, J. R., C. Lue-Hing, J. G. Gschwind, R. I. Pietz and D. R. Zenz, Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982, Page 327.

TABLE 28. SOIL ANALYSIS OF MINE SPOIL AND PLACELAND BEFORE AND AFTER SLUDGE APPLICATION

Soil analysis parameters (µg/g)	Cumulative sludge applied to fields			
	Mine spoil field		Placeland field	
	277.0 (t/ha)	0.0 (t/ha)	254.9 (t/ha)	0.0 (t/ha)
Organic carbon	3.89	0.61	2.84	1.64
Zn	687	31.7	446	31.4
Cd	51.6	0.2	32.6	.08
Cu	259	4.79	181	2.62
Cn	165	1.22	78	1.23
Ni	43.4	6.7	27.7	7.5
Pb	148	3.52	98	4.55
Mn	326	154	285	146
Al	1,455	509	1,172	540

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 29. SOLIDS AND NUTRIENT APPLICATIONS TO THREE RESPRESENTATIVE FIELDS AT THE FULTON COUNTY SITE

		Annual application			
Field number	Year	Sludge (t/ha)	TKN-N (kg/ha)	NH_3-N (kg/ha)	Total P (kg/ha)
23	1975	38.8	2,190	955	1,470
	1976	17.0	809	357	536
	1977	54.6	2,653	1,178	1,869
	1978	55.6	2,725	1,222	1,655
	1979	66.5	2,688	1,118	2,019
	1980	30.7	1,316	451	777
	*TOTAL	263.2	12,381	5,281	8,319
19	1973	3.6	813	688	308
	1974	36.7	1,874	1,065	918
	1975	19.7	1,113	486	743
	1976	50.2	2,383	1,054	1,580
	1977	41.4	2,011	893	1,417
	1978	37.4	1,834	823	1,114
	1979	74.6	3,014	1,253	2,264
	1980	98.3	4,219	1,446	2,468
	*TOTAL	361.9	17,261	7,708	10,817
15	1974	65.2	3,324	1,890	1,630
	1975	67.4	3,804	1,662	2,558
	1976	133.0	6,320	2,794	4,191
	1977	91.2	4,426	1,964	3,118
	1978	19.5	955	429	580
	1979	129.7	5,239	2,178	3,936
	1980	69.7	2,988	1,024	1,748
	*TOTAL	575.7	27,061	11,941	17,761

*TOTAL Represents total for years shown and not annual.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

Table 30 contains data for water samples collected in 1973 and 1979 from monitoring wells number 14 and 17 (15). Well number 14 is located in a field receiving sludge. Well 17 is located in a field where no sludge is applied. There are differences in the chemical constituents between the two wells. Some of these differences are due to previous strip mining on the site. The most significant data is the NO_2+NO_3-N concentration of the well water. The concentration of NO_2+NO_3-N has not changed in well number 14 from 1973 to 1979 indicating that application of sludge at the Fulton County site had not affected site groundwater.

Surface Water Quality

Monitoring of the largest stream, Big Creek, draining the Fulton County site was started in 1971. Samples were taken on Big Creek upstream, sampling point S1, and downstream, sampling point S2, of the Fulton County sludge application area. Table 31 shows constituent data for sampling points S1 and S2 on Big Creek (15). Sampling point S2 was of a better quality than S1, suggesting that drainage water from the Fulton County sludge application area was relatively clean. Also, sampling point S2 had relatively similar NO_2+NO_3-N, NH_3-N, and iron concentrations in 1973 and 1979, suggesting no significant change in water quality resulting from sludge application.

Under normal operating conditions the field runoff retention basins, previously described, are maintained in a drawn-down status. After a rainfall, runoff retention basins samples are analyzed for total suspended solids, 5-day biochemical oxygen demand (BOD), and fecal coliform counts. If the analyzed concentrations are within acceptable IEPA limits, the basin contents are discharged through control structures to the receiving stream. If the analyzed concentrations are not within acceptable IEPA limits, the basin contents are held until sufficient concentration reduction of the offending constituent is attained; or, at the discretion of the project manager, the basins contents are pumped back onto the field serviced by the river runoff retention basins (19).

Effluent data for all basins have been grouped into two classifications before and after digested sludge application to the fields. Table 32 summarizes the statistics of the effluent total suspended solids, 5-day BOD, and fecal coliform counts (19). This table shows that there is little difference in the quality of the retention basins effluent before and after sludge application in terms of the above-mentioned parameters. Table 32 shows some increase in the BOD_5 levels after digested sludge applications; however, the increase of about 4 mg/l is insignificant given the accuracy of the BOD_5 test in the 0 to 18 mg/l range (19).

TABLE 30. WEIGHTED AVERAGE WATER QUALITY OF WELL 14 AND WELL 17 AT THE FULTON COUNTY SITE

	1973		1979	
Constituent**	Well 14*	Well 17*	Well 14*	Well 17*
pH	7.1	7.6	7.0	7.7
Total P	0.12	0.08	0.06	0.04
Cl	19	10	19	13
SO_4	668	113	1,640	138
Total N	1.0	<1	0.7	< 0.2
NH_3-N	0.78	0.2	0.4	< 0.1
NO_2+NO_3-N	0.03	0.40	0.18	0.07
Alkalinity	741	305	774	262
Conductivity	2,806	745	2,891	796
K	6	1	7	< 1
Na	293	9	270	7
Ca	264	96	361	79
Mg	216	52	243	45
Zn	15.2	3.2	4.6	1.7
Cd	0.01	<0.01	0.01	< 0.01
Cu	0.02	0.01	< 0.01	0.02
Cr	< 0.02	<0.02	< 0.02	< 0.02
Ni	< 0.13	0.1	< 0.1	< 0.1
Mn	1.76	0.39	2.87	0.34
Pb	0.15	0.09	0.07	0.05
Fe	60.6	14.5	27.4	18.1
Al	< 1	<1	< 1	< 1
Hg	0.1	<0.1	< 0.1	0.1
Se	-	-	< 0.2	< 0.2
Fecal coliform	2	2	< 2	< 2
TSS	-	-	-	-
TDS	-	-	-	-

* Wells 14 and 17 are located in a field receiving sludge and a field receiving no sludge, respectively. Well 17 is 15.2 m deep and well 14 is 16.1 m deep.

** All units in mg/l except pH (pH units), fecal coliform (cnt/100 ml), conductivity (μmhos/cm) and Hg (ppb).

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1981.

TABLE 31. ARITHMETIC MEAN WATER QUALITY OF RECEIVING STATION S1* and S2* AT THE FULTON COUNTY SITE

	1973		1979	
Constituent**	S1	S2	S1	S2
pH	7.9	7.9	7.8	8.0
Total P	0.90	0.46	1.4	0.89
Cl	30	24	36	57
SO_4	269	308	493	562
Total -N	2.8	1.2	1.7	1.3
NH_3-N	0.78	0.59	0.9	0.4
NO_2+NO_3-N	3.12	2.57	3.1	2.17
Alkalinity	271	268	256	257
Conductivity	1,075	1,889	1,118	1,306
K	4	4	6	6
Na	53	66	71	85
Ca	130	174	149	145
Mg	67	109	55	72
Zn	< 0.1	< 0.1	< 0.1	< 0.1
Cd	< 0.01	< 0.01	< 0.01	< 0.01
Cu	0.02	0.02	< 0.01	< 0.01
Cr	< 0.02	< 0.02	< 0.02	< 0.02
Ni	< 0.1	< 0.1	< 0.1	< 0.1
Mn	0.53	0.50	0.41	0.42
Pb	0.04	0.05	.05	.05
Fe	1.2	1.1	0.8	0.8
Al	< 1	<1	< 1	< 1
Hg	< 0.1	<0.1	< 0.1	< 0.1
Se	-	-	< 0.2	< 0.2
Fecal coliform***	8,033	4,700	157	132
TSS	-	-	33	46
TDS	-	-	1,099	1,281

* S1 and S2 are stations on Big Creek upstream and downstream of the sludge application area of the Fulton County site, respectively.

** All units in mg/l except pH (pH units), fecal coliform (cnt/100 ml), conductivity (μ mhos/cm) and Hg (ppb).

*** Values given as geometric means of data collected.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 32. FIELD RUNOFF WATER QUALITY FROM FIELD RUNOFF RETENTION BASINS - FULTON COUNTY, ILLINOIS** SITE

Source	Total suspended solids (mg/l)	BOD (mg/l)	Fecal coliform (cnt/100 ml)
Runoff water before digested sludge applied			
Weighted average	63	2.8	102*
Std. deviation of weighted average	87	1.4	---
Minimum	1	1	0
Maximum	540	5	23,000
Runoff water after digested sludge applied			
Weighted average	60	6.0	35.6*
Std. deviation of weighted average	149	5.4	---
Minimum	1	2	0
Maximum	1,250	38	120,000

* Fecal coliform data reported as geometric mean.

** Used by permission of Water Pollution Control Federation.

Source: Zenz, D. R., J. R. Peterson, D. L. Broomon and C. Lue-Hing, Environmental Impacts of the Land Application of Sludge. Journal Water Pollution Control Federation, 48:2332-2342, 1976.

Crop Response to Sludge Application--

Corn is the principal crop grown on the site. Marketing of the corn helps to offset the sludge disposal costs. Crop yields have been variable and have ranged from excellent to nearly zero (Table 33) (18). Yields in 1976 were affected by a dry year (10 cm water for June and July) resulting in poor pollination. On strip-mined spoil, adequate moisture and essential elements are critical for crops grown immediately after land leveling. This inability to tolerate moisture stress gradually subsides as soil organic matter and nutrient levels are increased with successive sludge applications on strip-mined soils.

The concentration of cadmium in corn grain harvested from sludge-amended fields in Fulton County is shown in Table 34. With an approximate cadmium concentration in the applied sludge of 0.280 kg/t on a dry weight basis (Table 26), some fields have received 135 kg/ha of cadmium through 1979. In 1979, corn grain harvested from fields that had never received sludge had cadmium levels ranging from 0.04 to 0.46 μg/g (Table 35), whereas, cadmium levels in corn grain from sludge-amended fields ranged from 0.46 to 0.81 μg/g (Table 34). Cumulative cadmium applied to these sludge application fields ranged from 62 to 135 kg/ha and averaged 86 kg/ha.

Federal Regulations Concerning Sludge Application to Land--

Because of the U.S. EPA 1979 guidelines, the District elected to use the Fulton County site for the production of animal feed to avoid having to adhere to the cumulative cadmium application limitations.

Permits--

The District is required by the IEPA to have an operating permit for sludge application at the Fulton County site. From 1971 to 1975, the site had an IEPA operating permit. In 1975, however, the IEPA denied further operating permits to the District because of citizen complaints, and petitioned the Illinois Pollution Control Board (IPCB) to fine the District for alleged nuisance odors in 1974 and 1975. The IPCB, under Illinois law, has the sole authority to issue fines or impose corrective action.

Although the District did not have a permit from the IEPA from 1975 to 1981, the sludge application operations continued until the IEPA petition was ruled on by IPCB. The District, however, has not been allowed to develop any additional land for sludge application. The case before the IPCB was settled in 1981 and the Fulton County site was issued a new IEPA operating permit on January 1, 1982. This permit did not place any special restrictions on the District and the site will operate as it has in the past. The new permit, however, requires that the extensive monitoring program continue.

TABLE 33. CORN YIELDS IN SELECTED SLUDGE AMENDED FIELDS AT THE FULTON COUNTY, ILLINOIS SITE +(*)

Field type	Field number	Corn yields by year (t/ha) 1972	1973	1974	1975	1976	1977	1978	1979
Mine spoil									
	1	--	--	--	--	--	0.85	--	3.64
	2	--	--	--	2.95	--	--	1.37	--
	3	3.24	2.86	0.55	3.99	--	2.01	--	5.60
	5	--	--	--	--	--	1.16	--	--
	7	--	--	--	--	1.62	--	--	2.97
	25	--	--		--	2.39	--	--	4.10
	26	--	--	--	2.80	--	--	--	4.22
	28	--	--	--	--	--	0.70	--	--
	30	--	--	--	1.61	--	--	1.98	--
	34	--	4.12	--	--	5.32	--	--	--
Weighted average		3.24	3.49	0.55	2.84	3.11	1.18	1.68	4.12
Place-land	10	4.40	--	--	3.75	--	--	--	--
	19	5.72	0.76	1.60	--	--	6.26	--	--
	20	4.19	1.44	1.25	--	--	--	--	--
	21	5.12	0.54	0.58	--	6.46	--	--	--
	22	4.66	3.72	--	--	--	--	--	--
	23	7.45	2.16	--	--	3.85	--	--	--
	31	--	4.47	--	--	3.30	--	--	--
	35	--	5.35	--	3.37	--	--	--	--
	37	--	5.50	--	--	--	--	--	--
	40	--	--	--	--	--	--	--	--
Weighted average		5.26	2.99	1.14	3.56	4.54	6.26	--	--

(*) Used by permission of The Pennsylvania State University Press.

+ Commercial fertilizer was applied to fields 10 and 23 in 1972 and to fields 31, 34, 35, and 37 in 1973.

Source: Peterson, J. R., C. Lue-Hing, J. G. Gschwind, R. I. Pietz and D. R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982. 333 pp.

TABLE 34. CADMIUM IN CORN GRAIN FROM SLUDGE AMENDED FIELDS AT THE FULTON COUNTY, ILLINOIS SITE *

Field type	Field number	Cadmium in corn grain (μg/g)							Cadmium applied through each year (kg/ha)						
		1973	1974	1975	1976	1977	1978	1979	1973	1974	1975	1976	1977	1978	1979
Mine spoil															
	1	--	--	--	--	--	--	0.52	0.0	12	32	68	68	100	100
	2	--	--	0.29	--	--	0.63	--	0.0	16	28	66	93	103	133
	3	--	0.09	0.37	--	0.14	--	0.81	0.9	18	25	50	50	73	77
	5	--	--	--	--	0.69	--	--	0.5	16	42	66	66	81	102
	7	--	--	--	0.35	--	--	0.46	0.3	14	30	33	54	70	70
	25	--	--	--	0.22	--	--	0.65	0.0	6.4	26	26	62	86	94
	26	--	--	0.41	--	--	--	0.60	0.0	18	26	26	61	85	90
	28	--	--	--	--	0.52	--	--	0.0	11	36	64	64	86	124
	30	--	--	0.15	--	--	0.43	--	0.0	13	26	56	97	103	135
	34	0.01	--	--	0.37	--	--	--	0.0	0.0	22	27	48	64	81
	Weighted average	0.01	0.09	0.30	0.31	0.45	0.53	0.61	0.6	14	29	48	78	97	116
Place-land															
	10	--	--	0.10	--	--	--	--	0.0	17	31	51	73	90	108
	19	--	0.07	--	--	--	0.33	--	0.9	12	18	32	45	55	76
	20	--	0.66	--	--	--	--	--	0.2	15	21	33	43	59	79
	21	--	0.09	--	0.38	--	--	--	1.4	19	28	37	57	74	93
	22	--	0.06	--	--	--	--	--	0.5	4.6	13	27	32	48	66
	23	0.01	--	--	0.54	--	--	--	0.0	0.0	12	17	35	50	69
	31	--	--	--	0.50	--	--	--	0.0	4.8	34	38	58	77	99
	35	--	--	0.14	--	--	--	--	0.0	0.0	7.6	23	35	51	68
	37	0.02	--	--	0.32	--	--	--	0.0	4.7	25	30	47	63	86
	40	--	--	--	--	--	--	--	0.0	0.0	0.0	16	25	41	62
	Weighted average	0.02	0.22	0.12	0.44	--	0.33	--	0.8	11	21	30	45	61	81

* Used by permission of The Pennsylvania State University Press.

Source: Peterson, J. R., C. Lue-Hing, J. G. Gschwind, R. I. Pietz and D. R. Zenz, Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian, The Pennsylvania State University Press, University Park, Pennsylvania, 1982, Page 335.

TABLE 35. CADMIUM IN CORN GRAIN IN 1979 FROM FIELDS IN FULTON COUNTY WHICH NEVER RECEIVED SLUDGE*

Field number	Cd (μg/g)
Mined-spoil	
18	0.46
50	0.30
145	0.04
Weighted average	0.27
Non-mined land	
51	0.30
137	0.15
Weighted average	0.22

* Used by permission of The Pennsylvania State University Press.

Source: Peterson, J. R., C. Lue-Hing, J. G. Gschwind, R. I. Pietz and D. R. Zenz. Metropolitan Chicago's Fulton County Sludge Utilization Program. In: Land Reclamation and Biomass Production with Municipal Wastewater and Sludge, eds. William E. Sopper, Eileen M. Seaker, and Robert K. Bastian. The Pennsylvania State University Press, University Park, Pennsylvania, 1982. 336 pp.

Public Acceptance

In 1971, local officials in Fulton County encouraged the District to purchase the mined-spoil land and restore it for row crop agriculture. Cooperation of local officials has been excellent according to the District officials. The District established, in 1971, the Fulton County Steering Committee, comprised of public officials, representatives of organized civil groups, unattached private citizens and District staff personnel. At monthly meetings of the Steering Committee, post-site operation is summarized by District staff and any significant future operational changes are discussed. The meetings have been valuable for receiving public input for project operations and those attending have had favorable comments regarding the sludge application project. Additionally, unfavorable media and public concern about the site has diminished, thus the operation has apparently gained public acceptance.

Costs

The District maintains an accounting system for capital, and maintenance and operation costs. Annual costs for the Fulton County project are shown in Table 36 (15). The maintenance and operation (M&O) costs are actual expenditures for the Fulton County operation in 1980. Capital costs are actual contract amounts spent for capital expenditures. Monitoring costs, shown in Table 37 include the cost of operating a five person laboratory and sampling crew at the Fulton County site, and amortization of the building, plus the cost of analyzing samples at the District's laboratory at Stickney, Illinois (15). Land costs were computed for 1,881 ha or 30 percent of the acreage owned by the District in Fulton County. Only about 1,012 ha of land are actually receiving sludge at the Fulton County site, and about 870 ha are needed for roads, sludge storage, etc. Monetary returns from crop sales are based on receipts for the 1980 growing season and partially offset the sludge application/disposal costs. Unit costs for the operation of the Fulton County site are approximately $300/t. The transportation costs, monitoring costs, real estate taxes, and extensive site preparation costs would normally not be incurred by a municipal dedicated land disposal site and therefore total costs for the Fulton Company site may not be comparable to other sites.

Summary

The Fulton County site is being used to handle a portion of the District's sludge management problem. The District selected this site mainly because it was forced to find a repository for some of its sludge in the early 1970s due to a lack of sludge management options in the greater Chicago area. The site is located nearly 300 kilometers from Chicago and thus incurs large sludge transportation costs amounting to about half of the total sludge disposal cost.

The land had been strip mined and required extensive site preparation before sludge could be applied. The sludge application system used (sludge incorporation) was selected primarily for aesthetic reasons. The monitoring data indicate that sludge application has not had any significant environmental impact.

Local real estate taxes must be paid by the District, because the site is located outside its boundaries. The costs for transportation, extensive monitoring, payment of real estate taxes, and extensive site preparation, would normally not be incurred by a municipality for a dedicated land disposal site. Therefore, comparisons of cost components for the Fulton County site may not parallel direct cost components for other dedicated land sludge disposal sites.

TABLE 36. ANNUAL AND UNIT COSTS FOR FULTON COUNTY PROJECT (1980 DOLLARS)

Item	Annual costs ($)	Unit costs ($/t)++
A. M & O costs		
Loading and transporting sludge by barge to Fulton County +	7,251,470	146.47
Sludge application and farming costs ++	7,146,881	104.59
Monitoring costs (see table 37)	492,239	7.20
Taxes ++++	360,056	5.27
B. Capital costs		
Land costs +++	375,966	5.51
Site preparation +++++	795,694	11.64
Application and farming ++++++	822,279	12.03
Subtotal	17,244,585	292.71
Return on crops +++++++	(193,670)	(2.83)
TOTAL	17,050,915	289.88

+	49,509.6 Dry t were shipped in 1980.
++	68,333.6 Dry t were applied in 1980.
+++	Infinite life, 10%, 1,881 ha.
++++	1979 taxes paid in 1980.
+++++	20 years, 10%.
++++++	10 years, 10%.
+++++++	Actual receipts, 1980.
( )	Benefit or revenue

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

TABLE 37. FULTON COUNTY MONITORING ANNUAL COSTS (1980 DOLLARS)

Item	Costs ($)
Salaries and overhead	355,183
Consulting services	5,000
Equipment, supplies, and miscellaneous services	79,000
Vehicle maintenance and fuel*	5,000
Annual capital costs**	28,056
TOTAL	492,239

* Vehicles @ 5 years @ 10%.
** Building @ 20 year life @ 10%.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

SACRAMENTO REGIONAL COUNTY SANITATION DISTRICT LAND DISPOSAL OPERATION

Description of Sacramento Regional County Sanitation District (SRCSD) Wastewater Treatment Plant

The Sacramento Regional Wastewater Treatment Plant, constructed in April 1981, is designed to replace the existing 21 plants in the SRCSD to control wastewater discharges to the Sacramento River. This plant was scheduled for operation in September 1981. The Sacramento Regional Wastewater Treatment Plant will serve an estimated 750,000 residents by 1981. Major treatment processes in the new plant include primary sedimentation, pure oxygen activated sludge, secondary sedimentation, and chlorination for disinfection and dechlorination (using sulfur dioxide addition) prior to discharge to the Sacramento River (21).

The regional plant's solids handling system has several interesting features:

1. Screenings and grit are dewatered and incinerated and the ashes disposed of in an on-site landfill.

2. Scum is thickened and reclaimed.

3. Primary sludge, stormwater sludge (accompanying primary sludge) and secondary sludge are thickened, anaerobically digested, lagooned and then incorporated into an on-site dedicated land application site.

The basic unit operations of the solids management scheme for the Sacramento regional plant are discussed below.

Anaerobic Digester--

Flotation thickened secondary and primary sludge flows to nine complete mix anaerobic digesters at a solids concentration of about 4 percent. Average detention time in the digesters is 32 days. Digester temperature is controlled near 35°C (21). Sludge from the anaerobic digesters is fed to a "blending digester." The "blending digester" retention time is 3.0 days and its purpose is to prevent short-circuiting of undigested or raw sludge to twenty lagooons. Sludge from the "blending digester" is fed to a vacuum deodorizer for removing odorous gases from the digested sludge before it is discharged to the lagoons (21).

Sludge Lagoons--

The lagoons are divided into three batteries. Figure 5 shows the site layout for these lagoons. Batteries I and II have eight lagoons each, while Battery III has four lagoons. The total lagoon area is 51 ha. Battery I, lagoons I-5 and I-6, have been in continuous operation for the past 5 years (22).

Each of the three batteries of lagoons is to be surrounded by a 3.7 meter high impervious barrier of Cor-Ten steel. Each pair of lagoons is to be provided with a wind machine. The wind machines are located 3.7 m above the ground with blades 4.87 m across. These machines will be operated during low wind conditions and with the high barrier are designed to disperse and dilute possible odor emissions from the lagoons. The barrier serves to lift and mix the air current developed by the wind machines (21). Each lagoon will be equipped with two surface mixers which are designed to impart dissolved oxygen to the surface layer and minimize scum buildups. This mixing and dissolved oxygen input is expected to reduce odor emissions caused by anaerobic surface conditions and exposed scum (21). The entire odor control system for the sludge lagoons (barrier, wind machines and surface mixers) was developed after exhaustive field and laboratory tests conducted from 1976 through 1979.

Sludge Disposal--

Lagoon sludge will be disposed of on five 14.9 ha (actual usable ha) DLD sites located immediately adjacent to the sludge lagoons (Figure 5). Each site is bermed and drains to a 4,317 m^3 capacity detention basins. This basin is designed to accept a 10.16 cm rainfall event assuming an 80 percent runoff coefficient. Surface runoff can be discharged back to the treatment plant (24). Soil injection would be the disposal method used. A low ground pressure tractor will be used to pull a 201 m hose for sludge injection, at the rate of 50.4 l/sec, into the ground immediately behind the tractor. The injector, during the warmest period of the summer, is expected to traverse the same area twice per week. During the spring and fall, injection will be one pass per week per area. Sludge application is expected to total 224 t/ha/yr (24). This application rate will be used indefinitely by the SRCSD.

Description of the SRCSD Land Disposal Planning Studies

Introduction--

Planning for the plant's wastewater treatment and solids management systems began in 1973. The State of California Water Resources Council Board required a regional wastewater control program and a regional solids management plan for processing and disposing of the total solids production (grit, scum, screenings, primary sludge, secondary sludge, and stormwater sludge) of the Sacramento Regional Treatment Plant (21). After careful consideration of the regulatory constraints and the limitations at the proposed regional plant site, the SRCSD selected four solids management systems for detailed study for possible implementation at the regional plant. These four systems (21) were:

1. Lime stabilization and dewatering of scum, grit, screenings, and sludge with ultimate disposal in an off-site landfill.

2. Incineration of dewatered screenings, grit and scum. Anaerobic digestion of primary, secondary and stormwater sludge followed by dewatering of the digested sludge. Final disposal of incinerator ash and dewatered sludge in an off-site landfill.

3. Incineration of dewatered screenings, grit, scum, primary, secondary and stormwater sludge with disposal of the ash in an off-site landfill.

4. Incineration of dewatered scum, screenings, and grit and disposal of the ash in an off-site landfill. Digestion of primary, secondary and stormwater sludge followed by long-term storage in lagoons and final disposal of the sludge as a liquid for off-site agricultural use.

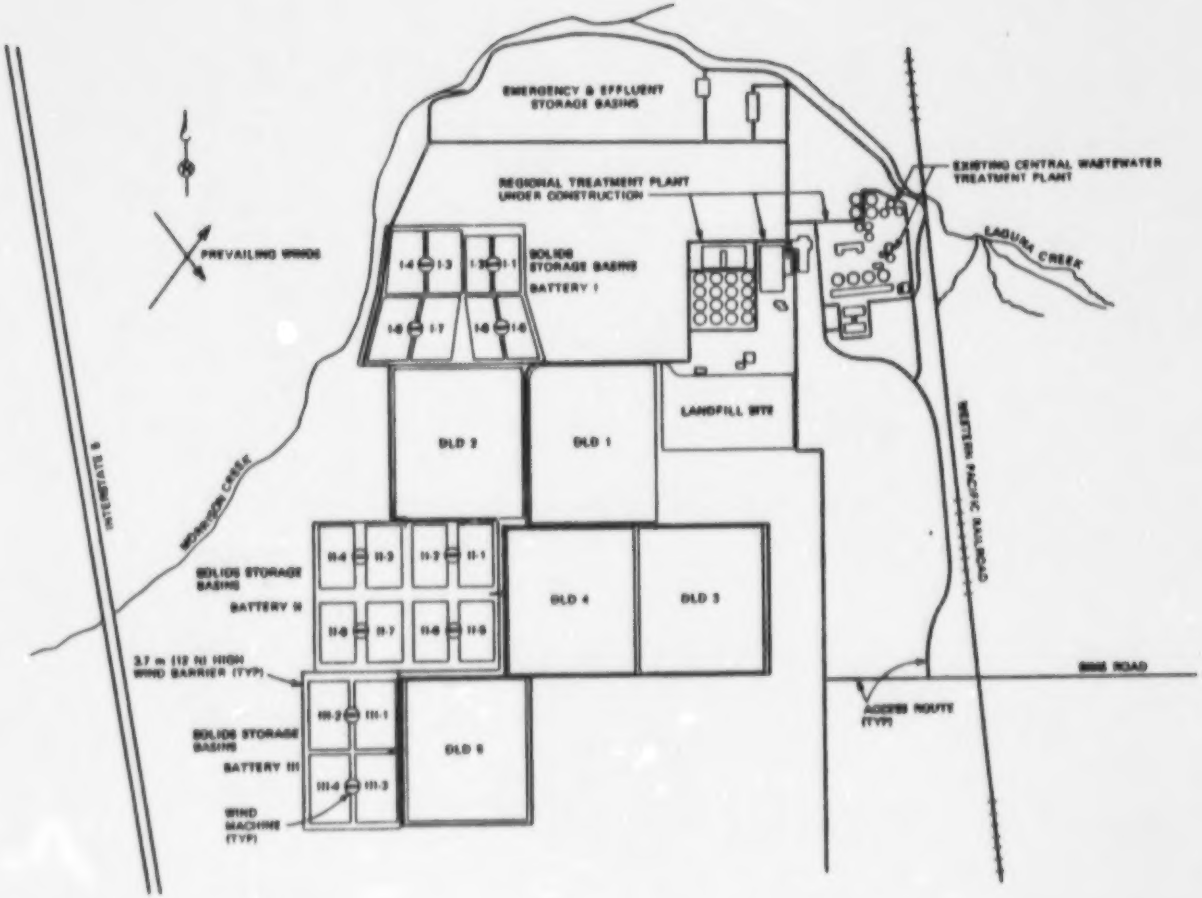
EMERGENCY & EFFLUENT
STORAGE BASINS
REGIONAL TREATMENT PLANT
UNDER CONSTRUCTION
EXISTING CENTRAL WASTEWATER
TREATMENT PLANT
LAGUNA CREEK
PREVAILING WINDS
SOLIDS
STORAGE BASINS
BATTERY I
I-1
I-2
I-3
I-4
I-5
I-6
I-7
I-8
LANDFILL SITE
DLD 1
DLD 2
DLD 3
DLD 4
DLD 5
WESTERN PACIFIC RAILROAD
MORRISON CREEK
INTERSTATE 5
SOLIDS STORAGE
BASINS
BATTERY II
II-1
II-2
II-3
II-4
II-5
II-6
II-7
II-8
3.7 m (12 ft) HIGH
WIND BARRIER (TYP)
SOLIDS STORAGE
BASINS
BATTERY III
III-1
III-2
III-3
III-4
WIND
MACHINE
(TYP)
ACCESS ROUTE
(TYP)
ROAD

Figure 5. Sacramento regional wastewater treatment plant solids treatment and disposal layout.

Alternative number 4 was the most promising and number 2 was second best. The most promising and second best alternatives involved separate incineration of dewatered screenings, grit and scum and the anaerobic digestion of primary, secondary and stormwater sludge. These facilities were, therefore, needed for immediate implementation into the final design of the regional wastewater treatment plant. However, it was recognized that questions remained regarding the implementation of alternative number 4, including regulatory constraints upon agricultural use of sludge and possible odor problems from this alternative.

A sewage sludge management study was planned to determine the environmental impacts and practicality of agricultural use of the sludge. The study was begun in the fall of 1975 and immediately encountered many obstacles, among these was an estimated study cost of $2.4 million and a 5-year completion schedule. There was also concern over the large agricultural land requirements estimated to be 4,400 to 6,600 ha. Because of these negative factors, the SRCSD decided to reexamine the alternative of agricultural use. In late 1975, two additional alternatives were considered. These were:

1. Anaerobic digestion of primary, secondary, and stormwater sludge and permanent lagooning of digested sludge.

2. Anaerobic digestion and primary, secondary and stormwater sludge and dedicated land disposal (high application rates and no cropping).

Finally, a comparison was made of the most viable alternatives in late 1975. These alternatives and their costs, energy, and land requirements, are summarized in Table 38 (21). Dedicated land disposal (DLD) required the least amount of land, had the lowest cost and nearly the lowest energy requirements. Permanent lagoons, the next best alternative, were rejected because the large amount of exposed water surface could result in potential odors (21).

The final decision to adopt dedicated land application for the Sacramento regional plant was therefore based upon the following reasons:

1. The time required to determine the environmental impact of agricultural usage was 5 years.

2. The land requirements for agricultural usage was excessive (up to 6,600 ha).

3. Costs for dedicated land disposal were lower than agricultural usage.

4. Permanent lagooning was rejected because of possible odor complaints.

TABLE 38. COMPARISON OF COSTS, ENERGY AND LAND USE IMPACTS OF FINAL ALTERNATIVES FOR SACRAMENTO, CALIFORNIA REGIONAL SOLIDS MANAGEMENT (ENR CONSTRUCTION COST INDEX = 2400)+

Alternative description	Average costs, ($/t dry solids)	Stage I energy consumed per day* (MJ)	Land required* (ha/yr)
Anaerobic digestion, storage, agricultural use	54.61	386	68.8**
Anaerobic digestion, dewatering, on-site landfill	64.46	564	9.51***
Anaerobic digestion, storage, permanent lagoons	49.90	329	5.46****
Anaerobic digestion, storage, on-site dedicated land disposal******	47.63	333	3.04*****

* Based on 56,600 t/yr for a 20-year program.
** Based on using 16.8 t/ha/yr dry weight, 20-year life.
*** Based on burying 3,140 t/ha/yr dry weight, 20-year life.
**** Based on storing 4,210 t/ha/yr dry weight, 20-year life.
***** Based on injecting 224 t/ha/yr dry weight, 20-year life.
****** Apparent best alternative.
+ Reprinted with permission to use.

Source: Brown and Caldwell, Dewarte and Stowell, J. B. Gilbert and Associates and the Spink Corporation. Draft Environmental Impact Report on Sewage Sludge Management Program. Wastewater Solids Processing and Disposal, Sacramento Regional Wastewater Management Program. October 1978.

Description of Dedicated Land Disposal Solids Management Study--

After the decision was made to pursue dedicated land disposal, studies of this sludge management option were conducted from 1976 through 1979 by a variety of consultants and the SRCSD staff. The complete dedicated land disposal system was not expected to be in operation until late 1981. The study had a variety of facets which are briefly discussed below.

Sludge application studies--The SRCSD plan called for stabilized sludge to be stored in facultative lagoons prior to dedicated land application. Sludge from these lagoons was applied to the 8.09 ha experimental dedicated land site. The 8.09 ha DLD site which was located on the site of the landfill noted in Figure 5 was abandoned at the end of 1979. This landfill is to be used for incinerator ash from the regional plant (23).

Sludge removal from the lagoons of Battery I to the 8.09 ha experimental site was accomplished by hydraulic dredge. This hydraulic dredge method will be used in the future. It is anticipated that solids concentrations approaching 8 percent will be possible during normal operation (22). Supernatant liquor from the lagoons is returned to the head end of the plant.

The SRCSD conducted field studies on the 8.09 ha site to determine the best means of incorporating liquid lagoon sludge. These studies involved experiments with direct injection of sludge below the soil surface, flood irrigation and controlled spreading of the liquid lagoon sludge with immediate soil incorporation with rotatilliers or plows, and ridge and furrow spreading of sludge (23). The 8.09 ha DLD site was monitored for surface and groundwater quality and soil characteristics. Sludge was taken from the existing central plant and applied to the site on a regular basis (23).

Environmental Monitoring Data

Introduction--

The data presented in this section are taken from studies conducted from 1976 through 1979 by the SRCSD on the 8.09 ha experimental DLD site located at the regional plant site.

Sludge Analysis--

Digested sludge from the existing central plant was placed in lagoons before land application at the DLD site. Typical lagoon sludge analyses are shown in Table 39 (23). The total nitrogen content was 5.9 percent, total phoshorus content was 1.9 percent (as P) and cadmium content was 19 (μ g/g dry weight).

TABLE 39. DIGESTED AND LAGOON SLUDGE ANALYTICAL DATA-SACRAMENTO REGIONAL PLANT SITE

Constituent	Units	Digested sludge*	Lagoon sludge*
Alkalinity**	mg/l	2,556	2,069
Chloride***	mg/l	143	171
Ammonia***	mg/l	444	573
Soluble phosphorus (P)***	mg/l	65	45
Sulfate***	mg/l	38	151
Total phosphorus (P)	%	1.8	1.9
Total nitrogen (N)	%	8.7	5.9
Calcium	μ g/g	21,556	24,000
Magnesium	μ g/g	5,800	8,600
Potassium	μ g/g	5,500	4,500
Sodium	μ g/g	9,200	5,400
Arsenic	μ g/g	47	15.4
Beryllium	μ g/g	2.2	1.3
Cadmium	μ g/g	12	19
Chromium	μ g/g	165	181
Copper	μ g/g	340	384
Lead	μ g/g	185	159
Mercury	μ g/g	3.7	5.6
Molybdenum	μ g/g	22	13
Nickel	μ g/g	63	77
Selenium	μ g/g	1.6	5.6
Silver	μ g/g	28	28
Zinc	μ g/g	930	1,200
PCB 1242	μ g/g	*****	2.1
PCB 1254	μ g/g	*****	4.6
Chlordane	μ g/g	*****	5.0
Other pesticides****	μ g/g	*****	0.7
Cd/Zn ratio	%	1.3	1.5
Total solids	%	1.7	4.1
Volatile solids of total	%	68	54
pH	pH units	7.5	7.4
Specific conductance***	μ mhos/cm	4,742	4,731

* Values are averages from samples collected during 1977.

** As $CaCO_3$, determined by potentiometric titration of supernatant.

*** Determined on supernatant, other determinations run on solution resulting from acid digestion of whole samples.

**** Other pesticides include residues such as DDT, DDE, dieldrin, etc.

***** Analysis not performed.

Heavy Metal and Nutrient Application Amounts--

The 8.09 ha site was mainly used to determine the most practical amount of sludge that could be applied to the DLD site. It was determined that amounts over 224 t/ha/yr could be applied. For the 224 t/ha/yr application rate, total nitrogen, phosphorus, and cadmium applications could approach 13,452 kg/ha/yr, 4,484 kg/ha/yr, and 4.48 kg/ha/yr, respectively. The nitrogen and phosphorus applications from sludge exceed the nutrient requirements of crops and the annual cadmium applications exceed the U.S. EPA (September 1979) limits of 0.50 kg/ha/yr.

Description of Experimental DLD Site--

The experimental DLD site originally had an uneven topography which sloped towards Morrison Creek which is near the site. Levees 4.57 m high were constructed around the site so that surface runoff could be collected and recycled to the central treatment plant (23).

In 1976, the site was leveled to a slope of 0.3 percent to the north. There was also a slight slope (0.04 percent) to the east. A drainage channel was constructed to carry runoff water along the north berm to a collection sump in the northeast corner. Trials in 1977 indicated that 0.3 percent slope was not adequate and the site was releveled. Starting from the south, the first 690.96 m sloped 0.8 percent, the second 60.96 m sloped 0.6 percent and the final 60.96 m sloped 0.4 percent (23).

Subsoil Conditions--

Fifteen backhoe holes were dug to a depth of approximately 1.8 m to evaluate the soil characteristics of the experimental DLD site before sludge application began. Two distinct soil series were found; namely, San Joaquin and Freeport. San Joaquin soils are shallow to moderately deep, hardpan soils. San Joaquin soil has a medium to strongly acid, brown to light brown loam upper surface soil and slightly acid, brown to reddish brown heavy loam lower surface layer. These surface soils overlie a neutral to mildly alkaline brown to reddish brown clay hardpan, located 15 to 36 cm thick, and rest on a silica-iron cemented hardpan which varies from 51 to 76 cm deep and is from 20 to 51 cm thick. Below the silica-iron hardpan, the soil is weakly consolidated and consists mostly of stratified sandy and silty layers. The hardpan soils impede water movement. San Joaquin soils are ideally suited for the spreading of sludge because the hardpan prevents deep percolation of drainage water (23).

The Freeport soils are moderately deep to deep dark colored clayed soils, which are underlain by a light colored siltstone or lime cemented hardpan-like material at a depth of 0.762 m or more. On wetting, Freeport soils swell and become nearly impermeable. This, coupled with the presence of the slight to moderately cemented subsoil, strongly impedes any downward movement of water. Under both the San Joaquin and Freeport soils, there are other dense layers which will further restrict or impede any deep percolating waters from reaching groundwater. Core samples were taken from four locations in the DLD site. The permeability of these cores ranged from 2.8 to 3.7 x 10^{-8} cm/sec. Soils with permeabilities of 10^{-7} cm/sec or less are considered to be impermeable (23).

It appears, therefore, that the entire DLD site has impermeable soil and that sludge disposal poses no hazard to usable groundwater supplies.

Fate of Sludge Heavy Metals at the Sacramento, California Regional Plant Site--

Sacramento sludge contains about 20 mg/kg of cadmium (Table 39). If 224 t/ha/yr are applied to the site, after twenty years the surface soil concentration could increase to 40 mg/kg, assuming no leaching from the top 15.2 cm of soil. However, because no crops of any kind will be grown on the DLD site, the high cadmium concentrations should not be a problem. Of course, such high cadmium levels would be an environmental concern if the land was ever returned to crop production.

Heavy metal concentrations in soil (top 15.2 cm) are shown for the experimental DLD site of 1976 through 1979 in Figure 6 (23). Soil metal levels are increased by the sludge application. Soil cadmium concentrations increased from less than 0.02 to about 0.75 mg/kg. Copper increased from 1.2 to 12 mg/kg, nickel from 1.1 to 3.1 mg/kg and zinc from 0.18 to 37.8 mg/kg. Because of the increase of soil metals caused by the projected 224 t/ha/yr sludge loading rate, the DLD site would not be suitable for food-chain crop production.

Fate of Polychlorinated Biphenyls and Chlorinated Hydrocarbon Species--

The levels of polychlorinated biphenyls (PCBs) and chlorinated hydrocarbon pesticides (as a group) from sludge application to a depth of 15.2 cm of soil from 1976 through 1979 are shown in Figure 7 (23). There is an increase in the levels of these constituents in the soil. However, soil samples at depths greater than 46 cm showed no detectable levels of pesticides because these organic types are fat soluble, insoluble in water, biogradable in the soil and are strongly held by clay colloids.

Cation Exchange Capacity and Organic Carbon Content of the Sacramento Site Soils --

The soil CEC and organic carbon levels in the top 15.2 cm of soil were measured in the spring (before sludge application began) and fall of 1976 at the experimental DLD site. Sludge application increased organic carbon levels of the soil from 0.25 to 0.7 percent from the spring to fall of 1976. Soil CEC remained unchanged for the same period at 28 meq/100g.

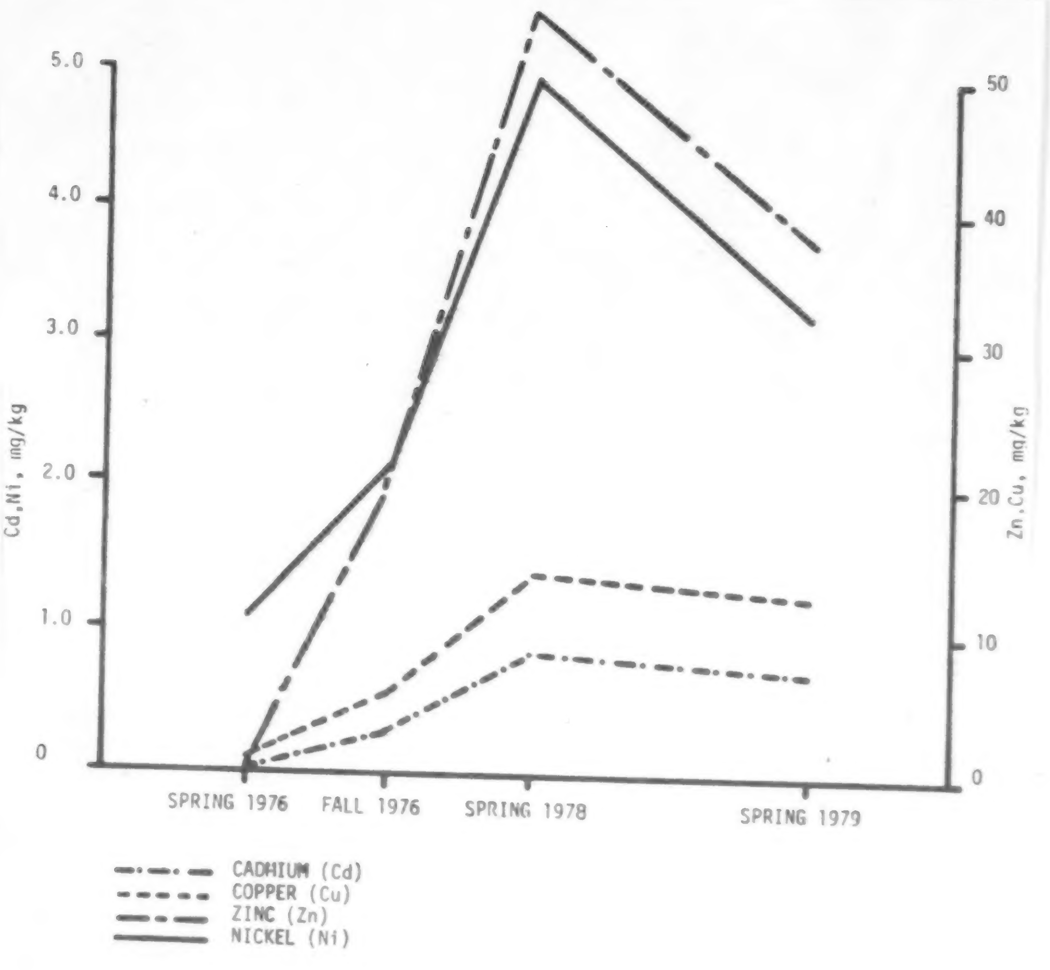

Figure 6. Average heavy metals in DLD soils, 0-15.2 cm of soil depth in Sacramento, California sludge application site soils.

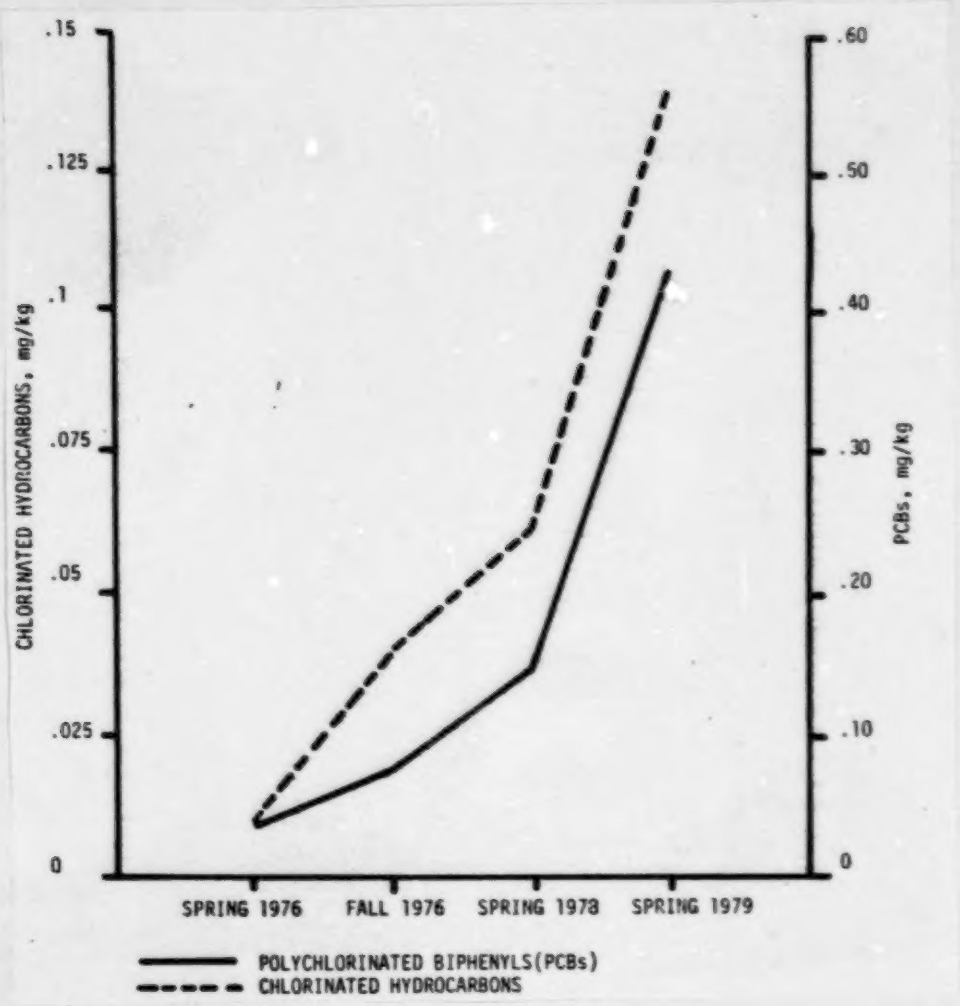

Figure 7. Average chlorinated hydrocarbons and polychlorinated biphenyls in DLD soils, 0-15.2 cm of soil depth in Sacramento, California sludge application site soils.

Runoff Analysis--

Runoff water samples were gathered during and immediately following rainfall events. Concentrations of constituents in the runoff water during the period of December 1977 through March 1978 are shown in Appendix D (23). No runoff occured during the dry winter of 1976 through 1977. In 1977 through 1978, the conductivity of the runoff water was initially quite high but later decreased. During the winter of 1978 through 1979, runoff occurred only once and the conductivity was quite low.

Phosphate in the runoff water was 27 mg/l in late 1977 and remained relatively constant thereafter. Chlorinated hydrocarbon pesticides and PCBs in the runoff water were at or below analytical detection limits. Heavy metals levels in runoff water were relatively low. Cadmium levels were below analytical detection limits. Although the runoff water contain high levels of nitrates and suspended solids, there is little chance of pollution of nearby streams because all surface runoff are collected and recycled to the treatment plant.

Groundwater Monitoring Data--

Groundwater monitoring wells were drilled to about 12.12 m below the ground surface and encased within PVC pipe. Selected constituent concentrations in the groundwater are shown in Appendix D for the period of the spring of 1977 to the spring of 1979 (24). The average concentrations of total dissolved solids and nitrates in groundwater increased sharply in 1979 primarily because one well showed very high levels.

Surface Injection Studies--

Various types of subsurface injectors for sludge application were tested at the experimental DLD site, however, one injector was found to give the best results. This injector covered a 4 m swath, averaged 1.6 km/hr, and covered 0.51 ha/hr of soil surface. This injector has a conventional tool bar, onto which nine "duck foot" shovels (sweeps) are mounted. A manifold distributes the sludge into feed hoses, each leading to the shovels. The sludge is pumped to the injector through a feed hose dragged along behind the injector. During normal operation, the sweeps run about 10.16 cm beneath the soil surface where they open a cavity into which the sludge pours. After the sweep has passed, the soil tends to go back into place, leaving the sludge virtually completely covered. The SRCSD concluded that 224 t/ha/yr was a practical application rate for their operation using this injector (23).

Other Methods of Sludge Application--

The SRCSD tested other methods of sludge application at the DLD site. The use of gravity flooding of fields previously ridged and furrowed was tested at the DLD site. Sludge was introduced into the furrows by gated pipe. While the sludge was flowing, a tractor with a furrow unit would split the ridges. However, this method of application was soon abandoned because of numerous problems (23). For example:

1. It was difficult to completely cover the sludge. This was undesirable because of possible odor generation.

2. The furrowing equipment repeatedly clogged with sticky subsoil and was constantly damaged.

3. Plugging of the gates with debris frustrated attempts for even flow of sludge to the furrows.

Flooding of the fields without ridge and furrows was also attempted. In these tests, sludge was applied by gated pipe to the high end of the fields. After flooding an agricultural disc would incorporate the sludge into the soil. Ordinarily, two discings were required. After a 24-hour rest period for drying, the field was disced a third time. So called "wild flooding" with no control of lateral movement was ineffective. The sludge spread unevenly and too far in a lateral direction. The use of "border checks," where 15.24 to 20.30 cm dikes were placed in the direction of flow was tried. Border checks tended to give better distribution but it often took 6 hours for the sludge to reach the bottom of the field. The sludge tended to build up too heavily at certain places in the field and, after discing, odors from these areas were evident. Flooding was abandoned by SRCSD staff as a possible application method (23).

Buffer Zones

The five DLD sites currently under construction will be at a minimum of 304.8 m from the boundary of SRCSD-owned land. There are about 768 ha of buffer land that surround the site to be used for sludge application. Approximately 50 percent of this buffer land is currently being leased to private landowners for seasonal grazing. The other 50 percent is used for producing a forage crop (21).

Neighboring Land Use

It is anticipated that land to the south of the DLD site where a 304.8 m buffer zone exists will remain in agricultural use. Land to the north, although currently in use as agricultural land, is expected to be urbanized as the Sacramento population moves farther out. Interstate Highway 5 lies parallel to the western boundary and a freeway interchange is planned for Interstate Highway 5 with a service road along the northern boundary of the plant site. The site is bordered on the east by Highway 99 (21).

Buffering for Odor Nuisance

The potential for odor nuisances was evaluated during the operation of the DLD experimental site. The SRCSD staff believe that the most critical odor factor is the operation of the sludge lagoons. However, the 609.6 m minimum distance between these sludge lagoons and the nearest possible neighbor and the elaborate odor devices (wind machines, 3.66 m barrier) are believed adequate to control odor (21).

Social and Aesthetic Issues

During the operation of the DLD experimental site, the SRCSD rarely received odor complaints. The SRCSD felt that any complaint could be traced to operations other than that connected with sludge disposal operations. There have been no odor complaints during the past 2 years.

Costs

Costs for the full-scale DLD site are not available because the DLD site is still under construction. Estimates of cost can be extrapolated to the full-scale DLD site from the operation of the 8.09 ha experimental DLD site. Table 40 shows a capital costs estimate developed for this study and operational costs are summarized in Table 41 (23).

Estimates of annual and unit costs are contained in Table 42 (23). Total unit costs for the Sacramento, California DLD program at the site are $47.22/t. Cost for the Sacramento site are relatively low because of the high sludge application rate (224 t/ha/yr), non-cropping of the site, low land costs and the use of seasonal and some non-union labor.

TABLE 40. CAPITAL COSTS -- SUBSURFACE INJECTION AT THE SACRAMENTO, CALIFORNIA SLUDGE APPLICATION SITE (1980 DOLLARS)

Description	Cost ($)
*Stationary equipment	806,307
Pipeline and valving	
Total stationary equipment	806,307
Land	
**Land purchase	396,000
***Land grading	688,049
Total land	1,084,049
Mobile equipment	
Two portable dredges	322,523
Two boosters	161,261
Four subsurface injectors	430,000
Tillage tractor	107,507
****Communications	10,750
Total mobile equipment	1,032,041
Total capital cost	2,922,397

* Includes piping and valving for moving sludge to the DLD site and conveyance of runoff water to the plant.

** 97.12 ha of land.

*** Grading of the site and construction of berms.

**** Radios for communication with the dredge.

TABLE 41. OPERATIONAL COSTS -- SUBSURFACE INJECTION AT THE SACRAMENTO, CALIFORNIA SLUDGE APPLICATION SITE (1980 DOLLARS)

Description	Cost ($)
*Labor-average 11 men, ½ year each	168,738.00
**Repairs and supplies	190,653.00
Fuel	25,201.00
Total operational costs	384,592.00

* One man for each dredge. One man for each injector and one man for each tillage tractor. Two men for relief of each injector and tractor operator and one man for supervision for a total crew of 11 men. Crew is billed for 50 percent of the year since sludge application is seasonable.

** Nine percent of the cost of injectors, tractors dredges and booster pumps. One percent of the cost of the pipeline. Fourteen hoses are needed each year. 2.24 t/ha/yr of lime to control soil pH.

TABLE 42. ANNUAL AND UNIT COSTS -- SUBSURFACE INJECTION AT THE SACRAMENTO, CALIFORNIA SITE (1980 DOLLARS)

Description	Annual costs ($)	Unit costs ($/t)***
Amortized capital cost		
*Stationary equipment	131,226.00	7.82
**Land and land grading	108,404.00	6.46
*Mobile equipment	167,965.00	10.01
Operational cost	384,592.00	22.93
Total cost	792,187.00	47.22

* 10 year life, 10 percent

** Infinite life, 10 percent

*** Based upon 16,768 dry t per year (224 t/ha on 74.86 ha)

SECTION 6

ANALYSIS OF COSTS FOR SLUDGE APPLICATION ON LAND

The following represents the major cost elements and factors which should be considered in an analysis of costs for sludge application on land:

1. Land costs.
2. Percent of land required for buffer.
3. Grading costs.
4. Fence costs.
5. Drainage and treatment of drainage.
6. Pumps.
7. Roads and access.
8. Labor rates.
9. Overhead rates.
10. Profit or non-profit.
11. Monitoring costs.
12. Energy costs.
13. Taxes or payments in lieu of taxes.
14. Cost of transporting sludge.
15. Interest rates.
16. Life expectancy of equipment and land.
17. Sludge treatment required specifically for land application.

18. Cost of fertilizer and value of sludge as fertilizer.

19. Regulatory and enforcement constraints.

20. Costs of alternative sludge disposal methods.

21. Cost recovery from sale of crops.

22. Public and farmer attitude to sludge application land.

23. Sludge application rates.

Table 43 contains a summary of sludge application and site data for the sites studied. Table 44 is a summary of costs of each sludge application site with the costs broken down by certain cost categories. Although considerable cost data are available for each of the sites, any direct cost comparison must take into account major differences in operational mode, major unit price differences, special local requirements and the lack of consistency in breaking down costs. These differences occur even within the three types of sludge application sites.

TYPE I SITES

Springfield and Toledo sludges are applied to privately owned lands at a cost to the cities of \$93/t and \$173/t, respectively. The city of Springfield personnel haul and apply the sludge whereas those functions are performed by a contractor for Toledo who also receives some payments from the farmers on whose land the sludge is applied. Sludge application rates are 5t/ha applied once in 3 years for Springfield and 11.2 t/ha applied once in 6 years for Toledo. Toledo dewaters sludge to 22 percent solids at a cost of \$98/t prior to transport to farms approximately 60 km from the plant. Springfield sites are 10 km from the plant. At both sites, farmers receive nutrients at costs less than commercial fertilizers; however, the cost differential should take into account any limitations on land use created by sludge application and any premium the farmers should receive for departing from "normal" practice.

TYPE II SITES

Like the Type I sites, the costs at the two Type II sludge spreading sites in Springfield and Hanover Park, Illinois also are markedly different; costs are \$51/t at Springfield and \$211/t at Hanover Park. However, the two sites represent markedly different sludge disposal situations. The Springfield, Illinois site required relatively little site grading and land preparation for spray application of sludge, while the Hanover Park site had precision sloped fields for gated pipe sludge application. Land costs for the Springfield site were low, however, the Hanover site exists in a

TABLE 43. SUMMARY OF SLUDGE APPLICATION AND SITE DATA

Item	Type I		Type II		Type III	
	Springfield, Ohio	Toledo, Ohio	Springfield, Illinois	Hanover Park, Illinois	Fulton County Illinois	Sacramento, California
Application rate, dry solids:						
t/ha	5	11.2	76	34-45	44-83	224
N, kg/ha	150	230	2,700	1,480	3,900	13,450
Cd, kg/ha	0.2	0.22	1.2	1.74	86	4.5
P, kg/ha	-	330	128	-	2,539	4,500
Application frequency, years	3	6	1	1	1	1
Sludge characteristics:						
Solids - %	6.9	22	1-2	2.44	6	4.1
N - % of DS	3	2	*	5-7	4	5.9
P - % of DS	1.8	2.9	*	1.5-2	3	1.9
Cd - mg/kg	39	20	*	10-120	280	19
Haul distance (km)	20†	121 †	Onsite	Onsite	321 ≠	Onsite
Amount of land	47ξ	900 #	15	81	1,881	8

*Sludge applied in liquid form.

† Round trip.

≠One way.

ξ Each year for 3 years.

#Each year for 6 years.

TABLE 44. SUMMARY OF COSTS OF EACH SLUDGE APPLICATION SITE DATA (1980 DOLLARS)

	Type I		Type II		Type III	
Item	Springfield, Ohio ($/t)	Toledo, Ohio ($/t)	Springfield, Illinois ($/t)	Hanover Park, Illinois ($/t)	Fulton County Illinois ($/t)	Sacramento, California ($/t)
Application and transportation	$93.00	$68.00	$45.00*	$ 35.00*	$275.00	$41.00
Monitoring	-	7.00	-	4.00	7.00	-
Land	-	-	6.00	69.00	6.00	6.00
Construction	-	-	-	119.00 Δ	-	-
Taxes	-	-	-	-	5.00	0
Sludge dewatering		98.00				
Total Cost	93.00	173.00	51.00	226.00	293.00	47.00
Revenue from crops	-	-	-	15.00	3.00	-
Net Cost	$93.00 †	$173.00 †	$51.00	$211.00	$290.00	$47.00

* Includes only the application cost.
† Farmer-derived benefit from use of sludge.
Δ Amortized, 20 year life, 10%.

relatively affluent suburb of metropolitan Chicago where the cost for the 80.93 ha of land required was high. The Springfield site can use spray application of sludge because of its isolated location. The Hanover site requires gated irrigation pipe for sludge application to reduce sludge visibility and minimize citizen complaints. Springfield has relatively lower labor costs for sludge application while the Hanover site is in an area where labor costs are on a generally higher scale. The sludge application rate used at Springfield is nearly double the Hanover Park rate. The Springfield, Illinois, site has no monitoring costs available, but monitoring costs should be less than $6.00/t based upon the cost of monitoring for the other sites studied. Some Hanover Park costs are recovered by sale of crops.

TYPE III SITES

The two Type III sludge application sites also show a wide range of costs. There are wide differences in the two operations at the Fulton County, Illinois, and Sacramento County, California, sites where the costs are $290/t and $47/t, respectively. The Sacramento site operation does not incur transportation costs while the Fulton county site operation is 321 km from the District's point of sludge generation in Chicago. Capital and land costs are quite similar, because both operations are located in rural communities and both use a soil incorporation method. Although no costs are available for monitoring at Sacramento, it was assumed that these costs would be similar to those of the other sludge application operations where monitoring costs are available, and would probably be less than $6.00/t. There are large differences in the cost for sludge application to land. These differences are due to the relatively inexpensive seasonal labor used in Sacramento, California, while the Fulton County, Illinois, site utilizes relatively expensive labor from nearby Peoria, Illinois.

The Fulton County site, unlike all the other sites, pays real estate and other taxes, equal to $5.27/t, because it is located outside the political boundaries of the operating government agency where sludge is generated. Under Illinois law, the Fulton County site is considered to be owned and operated by a private concern and thus subject to the taxing authority of the County of Fulton. Sale of crops at Fulton County results in recovery of $2.83/t of the sludge disposal costs.

A comparison of the costs associated with the three types of dedicated land sludge disposal scenario reveals that costs of sludge transportation to a dedicated site far removed from the treatment plant (the Fulton County site) exceed the costs of sludge application. It appears also that the costs for sludge concentration resulting from efforts to reduce transportation and storage costs (the Toledo site) can be high in comparison to total costs associated with dedicated land disposal. Based upon the data compiled at two of the DLD sites, revenue from cropping represents an insignificant portion of DLD sites total costs.

It is not possible to determine, from the cost data compiled for the six sites studied, the relative cost effectiveness of the three types of DLD sites. The cost data compiled are influenced mainly by local conditions and sometimes were dictated by social and aesthetic factors.

An analysis of the data from all six sites (Tables 43 and 44) indicates that the most important cost factors in comparing costs per metric ton of sludge (dry solids) are:

1. Special site preparation costs which may be necessary because of the method of sludge application, drainage control and/or aesthetic or other public attitudinal considerations.

2. Land costs including land required for buffers.

3. Transportation costs which would be affected by distance and moisture content of sludge. An engineering economic analysis would determine the relative advantages of sludge dewatering.

4. Market place costs, competition and local attitudes to sludge application/disposal on land. Contract costs are subject to the competitive bid process; however, the price that would be paid for land disposal would be affected by the availability and cost of alternative sludge disposal methods.

5. Labor rates where the project is labor intensive.

Major cost factors which affect all sites are: (1) the cost of money or the interest rate on borrowed funds; (2) the relative amounts of capital costs, and (3) operation and maintenance costs. And finally, any evaluation or cost comparison must take into account the costs/prices of available alternative sludge disposal methods.

REFERENCES

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APPENDIX A

ENVIRONMENTAL PROTECTION AGENCY REGULATIONS ON CRITERIA FOR CLASSIFICATION OF SOLID WASTE DISPOSAL FACILITIES AND PRACTICES (40 CFR 257; 44FR53460; 44FR54708; 44FR58910; AMENDED BY 46FR47051, September 23, 1981)

INTRODUCTION

Solid waste disposal facilities or practices must meet criteria related to the following:

1. Floodplains
2. Endangered species
3. Surface waters
4. Ground water
5. Application to land used for the production of food-chain crops
6. Disease
7. Air, and
8. Safety

The criteria includes dedicated sludge disposal sites used for production of food-chain crops. "Food-chain crops" means tobacco, any crops grown for human consumption, and feed for animals whose products are consumed by humans. A facility or application of solid wastes for the production of food-chain crops should not exist unless it is in compliance with all of the requirements related to cadmium listed under A or B below.

Requirements A

1. The pH of the solid waste and soil mixture is 6.5 or greater at the time of each solid waste application, except for solid waste containing cadmium at concentrations of 2 mg/kg (dry weight) or less.
2. The annual application of cadmium from solid waste does not exceed 0.5 kilograms per hectare (kg/ha) on land used for production of tobacco, leafy vegetables or root crops grown for human consumption. For other food-chain crops, the annual cadmium application rate does not exceed:

Time period	Annual Cd application rate (kg/ha)
Present to June 30, 1984	2.0
July 1, 1984 to December 31, 1986.......	1.25
Beginning January 1, 1987...............	0.5

3. The cumulative application of cadmium from solid waste does not exceed the levels in either paragraph (a) of this section or paragraph (b) of this section.

Paragaph (a)--

Soil cation exchange capacity (meq/100g)	Maximum cumulative application (kg/ha) Background soil pH (< 6.5)	 Background soil pH (≥ 6.5)
5....................	5	5
5-15....................	5	10
15....................	5	20

Paragraph (b)--

For soils with a background pH of less than 6.5, the cumulative cadmium application rate does not exceed the levels below. Provided, that the pH of the solid waste and soil mixture is adjusted to and maintained at 6.5 or greater whenever food-chain crops are grown.

Soil cation exchange capacity (meq/100g)	Maximum cumulative application (kg/ha)
5.............................	5
5-15.............................	10
15.............................	20

Requirements B

1. The only food-chain crop produced is animal feed.

2. The pH of the solid waste and soil mixture is 6.5 or greater at the time of solid waste application or at the time the crop is planted, whichever occurs later, and this pH level is maintained whenever food-chain crops are grown.

3. There is a facility operating plan which demonstrates how the animal feed will be distributed to preclude ingestion by humans. The facility operating plan describes the measures to be taken to safeguard against possible health hazards from cadmium entering the food chain, which may result from alternative land uses.
4. Future property owners are notified by a stipulation in the land record or property deed which states that the property has received solid waste at high cadmium application rates and that food-chain crops should not be grown, due to a possible health hazard.

Polychlorinated Biphenyls (PCBs)

Solid waste containing concentrations of PCBs equal to or greater than 10 mg/kg (dry weight) is incorporated into the soil when applied to land use for producing animal feed, including pasture crops for animals raised for milk. Incorporation of the solid waste into the soil is not required if it is assured that the PCB content is less than 0.2 mg/kg (actual weight) in animal feed or less than 1.5 mg/kg (fat basis) in milk.

APPENDIX B

ADDITIONAL INFORMATION ON THE SUGAR CREEK LAND DISPOSAL SITE

Soil profile and bulk density measurements for the Sugar Creek site of the Springfield, Illinois Sanitary District are given in Figure 8 and Table B-1, respectively.

TABLE B-1. SOIL BULK DENSITY MEASUREMENTS--
SUGAR CREEK SITE

Depth, cm	Bulk Density (g/cm)	Porosity (%)
0-25	1.27	53.0
25-50	1.41	48.0
51-75	1.65	39.0

Source: Alvey, Robert A. Effects of Aerobic Sludge Disposal on Land. Presented at the 1979 Annual Water Pollution Control Federation Conference in Houston, Texas, October 1979.

* Reprinted with permission to use.

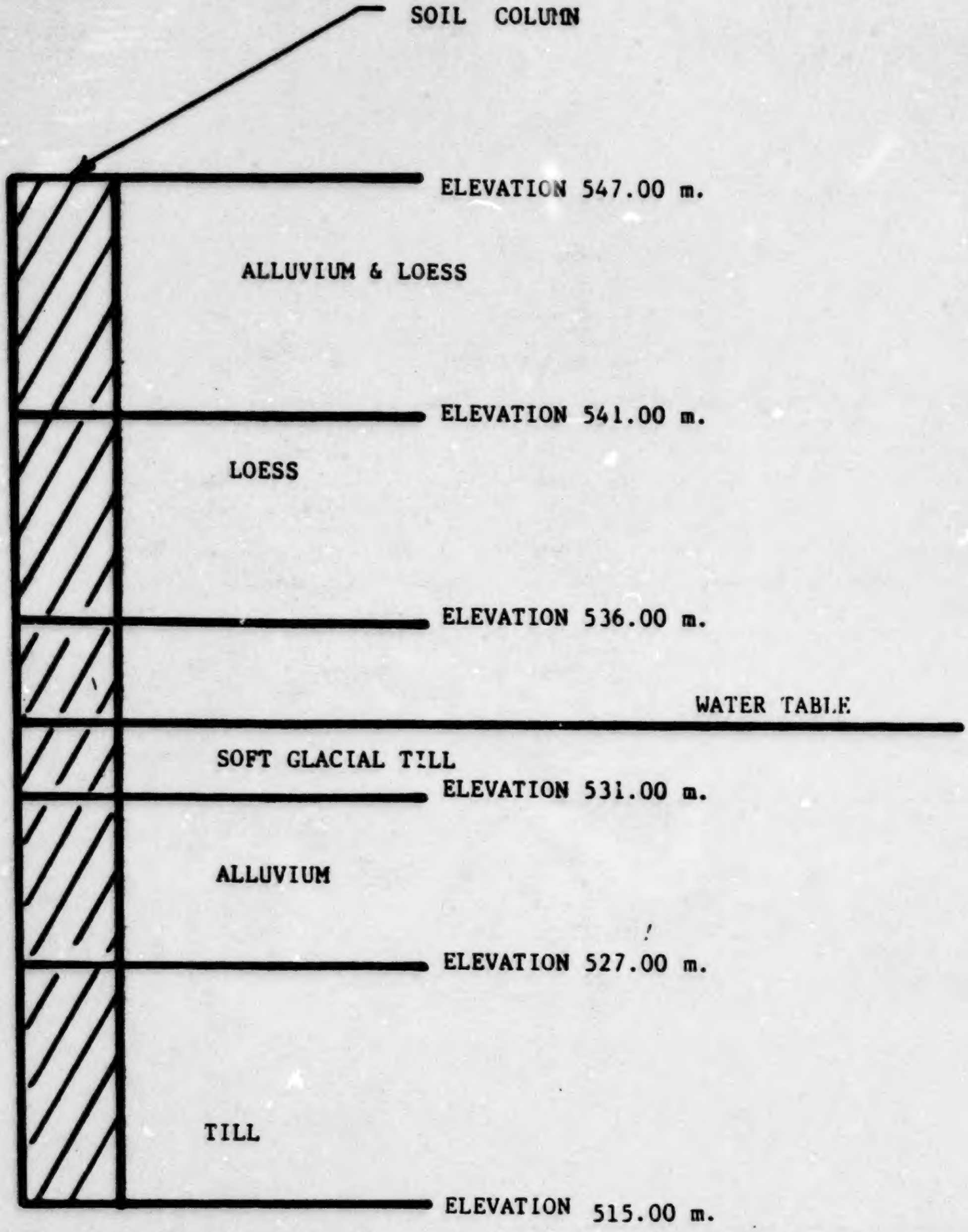
SOIL COLUMN
ELEVATION 547.00 m.
ALLUVIUM & LOESS
ELEVATION 541.00 m.
LOESS
ELEVATION 536.00 m.
WATER TABLE
SOFT GLACIAL TILL
ELEVATION 531.00 m.
ALLUVIUM
ELEVATION 527.00 m.
TILL
ELEVATION 515.00 m.

Figure 8. General soil profile and bulk density of the Sugar Creek and Springfield, Illinois site.

APPENDIX C

ADDITIONAL INFORMATION ON THE FULTON COUNTY LAND DISPOSAL SITE

A schematic soil profile of the Fulton County site is given in Figure 9. Air ammonia concentrations at the site are given in Table C-1.

TABLE C-1. THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO MONTHLY AIR AMMONIA AND TEMPERATURE VALUES AT FULTON COUNTY SLUDGE HOLDING BASINS FOR AUGUST 1973 THROUGH SEPTEMBER 1980

		NH_3			Air temperature +		
Year	Month	Weighted average (ppm, v/v)	Range (ppm, v/v)		Weighted average (°C)	Range (°C)	
1973	August	1.85	0.42	3.62	28.1	21.1	35.0
	September	2.04	0.76	8.54	23.0	14.4	29.4
	October	0.95	0.42	1.64	20.6	11.7	27.2
	November	0.51	0.10	1.28	8.9	-1.1	18.3
	December	0.29	0.17	0.67	1.2	-6.7	15.6
1974	January	0.11	0.00	0.51	-1.2	-13.9	16.7
	February	0.19	0.08	0.42	-0.3	-6.7	8.3
	March	0.71	0.00	2.25	8.5	1.1	21.7
	April	0.82	0.34	1.85	13.0	2.2	21.1
	May	1.22	0.34	1.92	17.9	11.5	26.0
	June	1.93	0.94	2.86	23.7	18.5	29.0
	July	2.59	0.46	4.16	28.6	23.5	32.5
	August	1.75	0.51	3.19	25.8	19.5	31.5
	September	1.13	0.52	1.93	18.8	8.5	26.5
	October	1.91	0.37	1.38	16.9	10.5	21.0
	November	0.49	0.07	1.11	9.0	1.5	24.5
	December	0.23	0.08	0.51	3.4	-1.0	9.5

continued

TABLE C-1 (Continued)

		NH_3			Air temperature +		
Year	Month	Weighted average (ppm, v/v)	Range (ppm, v/v)		Weighted average (°C)	Range (°C)	
1975	January	0.16	0.00	0.24	1.5	-7.0	13.0
	February	0.18	0.00	0.73	1.6	-3.0	10.0
	March	1.40	0.10	0.47	3.9	-4.0	15.0
	April	0.36	0.05	0.73	13.2	3.0	23.5
	May	1.16	0.28	3.29	22.0	17.0	28.5
	June	1.66	1.06	2.30	25.5	21.5	29.0
	July	1.16	0.36	1.96	27.9	21.5	35.0
	August	1.28	0.27	1.67	28.7	22.0	36.0
	September	0.83	0.21	1.87	19.4	11.5	30.0
	October	0.71	0.10	1.47	17.8	13.5	25.5
	November	0.61	0.22	1.35	10.0	3.0	20.8
	December	0.19	0.00	0.38	0.7	-9.0	14.0
1976	January	0.09	0.00	0.16	-1.8	-17.0	7.0
	February	0.11	0.00	0.18	3.5	-10.0	17.0
	March	0.29	0.16	0.37	8.7	-2.0	19.5
	April	0.47	0.23	0.85	15.2	9.5	20.5
	May	1.66	0.59	3.39	17.4	9.0	24.5
	June	2.41	1.49	3.93	24.0	20.5	30.0
	July	2.33	1.62	3.92	28.1	25.0	31.5
	August	1.26	0.69	2.53	25.4	20.5	28.0
	September	0.87	0.41	1.86	23.1	16.5	31.5
	October	0.43	0.02	1.55	10.3	4.5	20.0
	November	0.42	0.03	1.05	3.6	-11.0	11.0
	December	0.16	0.02	0.54	-2.9	-12.0	5.5

continued

TABLE C-1 (continued)

		NH_3			Air temperature +		
Year	Month	Weighted average (ppm, v/v)	Range (ppm, v/v)		Weighted average (^{o}C)	Range (^{o}C)	
1977	January	0.08	0.00	0.26	-8.6	-15.0	-2.0
	February	0.04	0.00	0.15	2.3	-8.0	10.5
	March	0.24	0.00	0.51	9.9	4.0	16.0
	April	0.76	0.28	1.44	20.4	9.0	28.0
	May	0.83	0.26	2.26	24.4	14.0	35.0
	June	1.28	0.54	2.44	22.8	16.5	30.0
	July	1.31	0.50	2.51	28.9	23.0	37.0
	August	0.85	0.22	1.89	25.0	20.0	30.0
	September	0.99	0.22	1.93	21.8	17.5	27.5
	October	0.88	0.08	1.97	16.8	11.0	20.0
	November	0.56	0.25	1.17	9.2	-7.0	21.0
	December	0.09	0.00	0.29	2.2	-5.0	8.0
1978	January	0.05	0.00	0.34	-3.1	-11.0	5.0
	February	0.13	0.00	0.42	-4.8	-9.5	4.0
	March	0.13	0.00	0.46	5.4	-4.5	14.0
	April	0.43	0.08	0.75	16.6	10.0	27.0
	May	2.11	0.26	5.48	22.2	14.0	29.0
	June	2.78	0.69	7.33	25.9	22.5	30.0
	July	3.82	1.22	6.97	27.0	22.5	31.0
	August	2.30	1.15	4.31	27.3	25.0	31.0
	September	3.76	1.94	8.32	25.3	18.5	28.5
	October	1.33	0.39	4.81	16.8	9.0	25.0
	November	0.64	0.06	1.16	8.2	-1.0	23.0
	December	0.25	0.00	0.61	1.9	-10.0	11.0

continued

TABLE C-1 (continued)

		NH_3			Air temperature +		
Year	Month	Weighted average (ppm, v/v)	Range (ppm, v/v)		Weighted average (^oC)	Range (^oC)	
1979	January	0.28	0.06	0.72	-6.8	-16.0	2.5
	February	0.10	0.03	0.19	-4.6	-14.0	3.0
	March	0.36	0.02	1.26	7.3	0.0	18.0
	April	1.68	0.26	2.59	11.6	2.5	23.5
	May	2.37	0.18	6.94	19.4	10.5	28.0
	June	0.87	0.01	4.07	25.9	18.0	32.0
	July	0.51	0.03	1.84	30.1	23.0	34.5
	August	1.40	0.04	3.02	27.1	22.0	34.0
	September	0.89	0.10	2.32	25.9	18.5	32.5
	October	0.70	0.01	1.77	14.3	3.5	21.0
	November	0.21	0.06	0.74	7.8	-2.0	21.0
	December	--	--	--	--	--	--
1980	January	--	--	--	--	--	--
	February	--	--	--	--	--	--
	March	--	--	--	--	--	--
	April	0.61	0.13	1.81	14.6	1.0	24.5
	May	0.77	0.01	3.65	23.4	15.0	31.0
	June	0.51	0.05	1.22	26.9	21.0	34.0
	July	1.24	0.29	2.96	32.3	29.0	39.0
	August	0.85	0.10	1.93	31.1	26.0	37.0
	September	0.52	0.10	0.99	24.3	18.0	33.5

+ Taken at air ammonia sampling site.

Source: Personal communication, Metropolitan Sanitary District of Greater Chicago, 1979 through 1981.

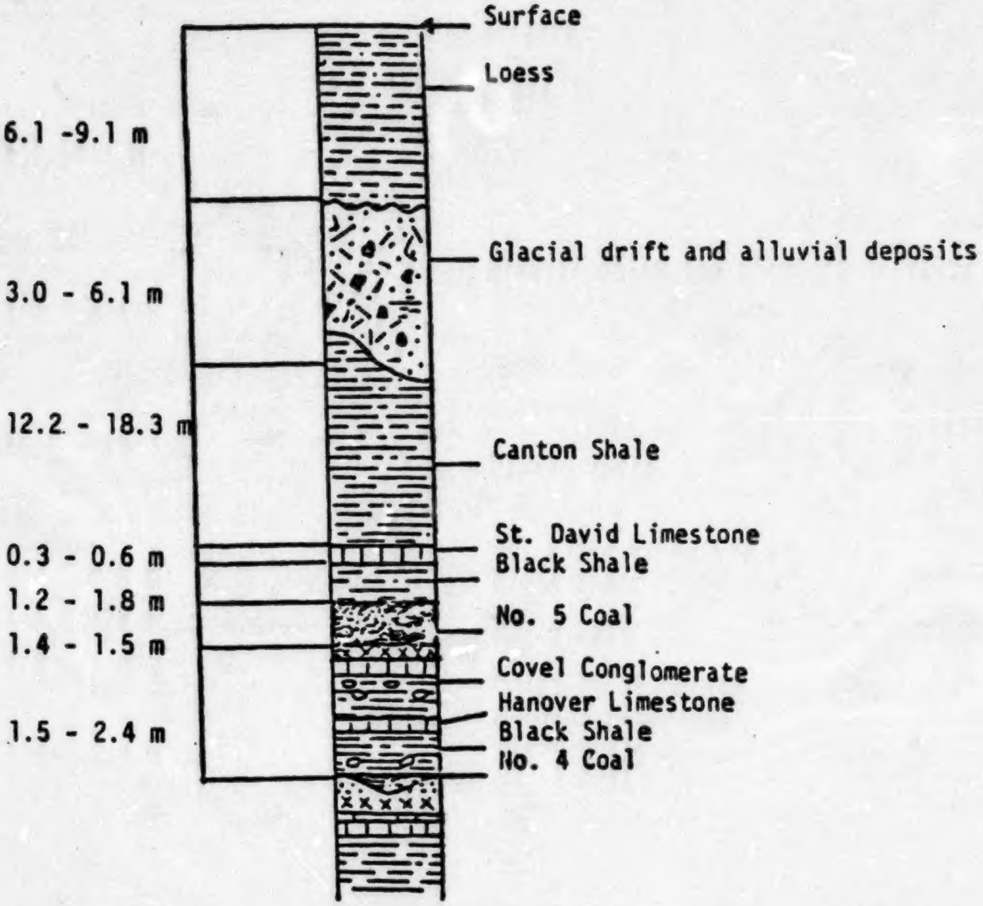
Surface
Loess
6.1 -9.1 m
Glacial drift and alluvial deposits
3.0 - 6.1 m
12.2 - 18.3 m
Canton Shale
St. David Limestone
0.3 - 0.6 m
Black Shale
1.2 - 1.8 m
No. 5 Coal
1.4 - 1.5 m
Covel Conglomerate
Hanover Limestone
1.5 - 2.4 m
Black Shale
No. 4 Coal

Figure 9. Typical stratigraphic profile at the Fulton County site.

APPENDIX D

ADDITIONAL INFORMATION ON THE SRCSD LAND DISPOSAL SITE

Figures 10 and 11 show the concentration variations of selected constituents in groundwater over a period of time at the site, and Figures 12 and 13 show the concentration variations of selected constituents in the runoff water over a period of time from the site.

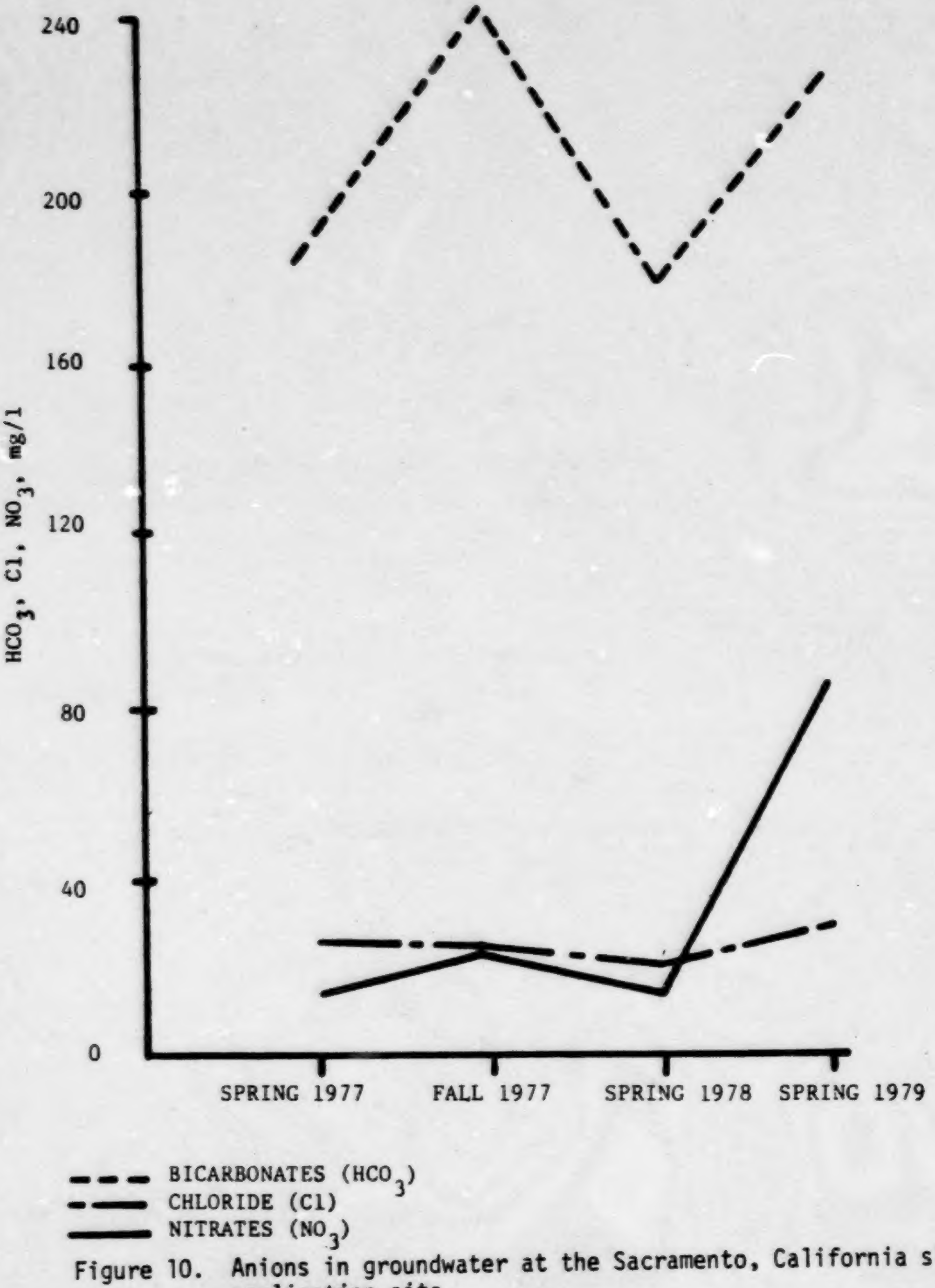

Figure 10. Anions in groundwater at the Sacramento, California sludge application site.

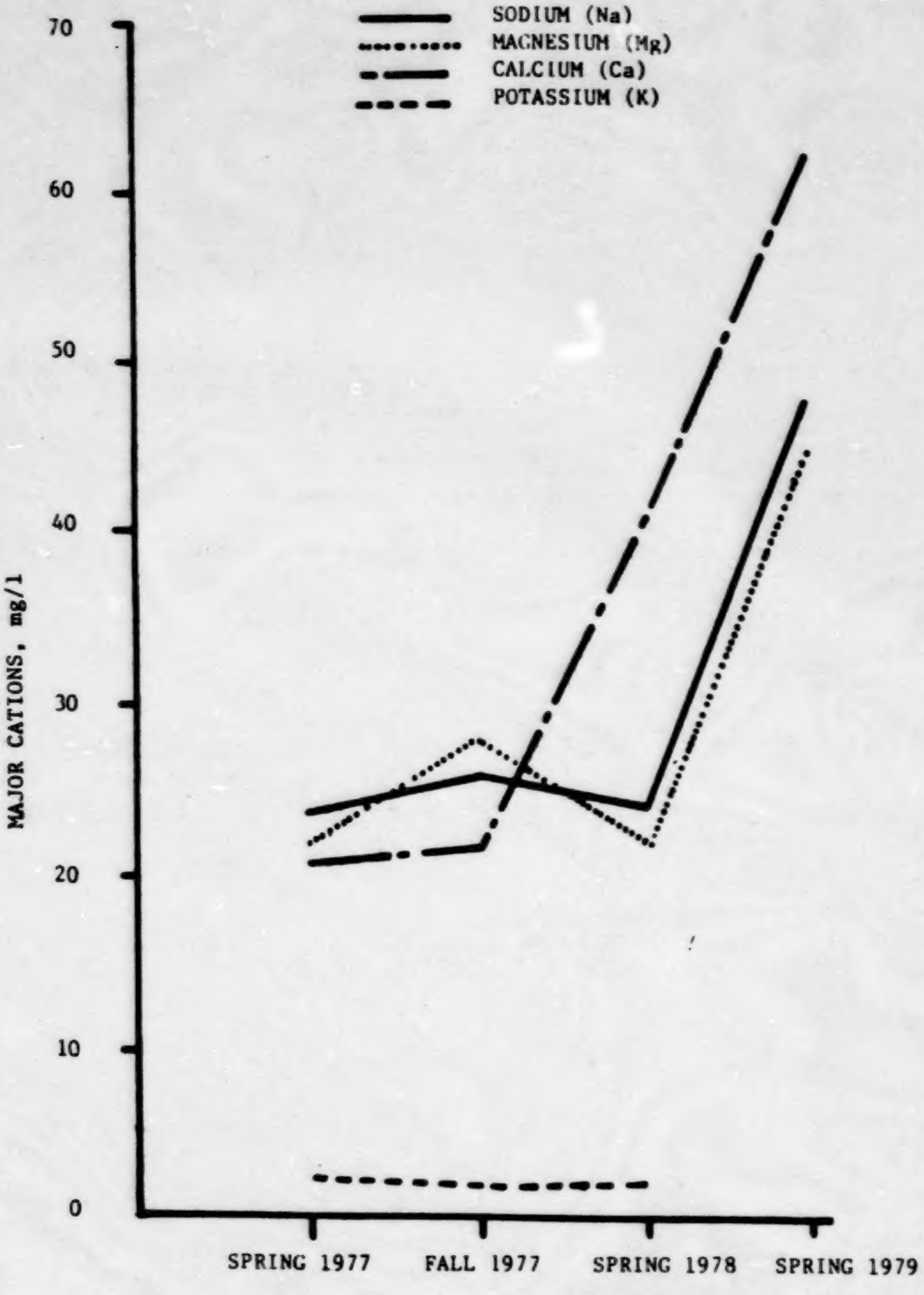

Figure 11. Major cations in groundwater at the Sacramento, California sludge application site.

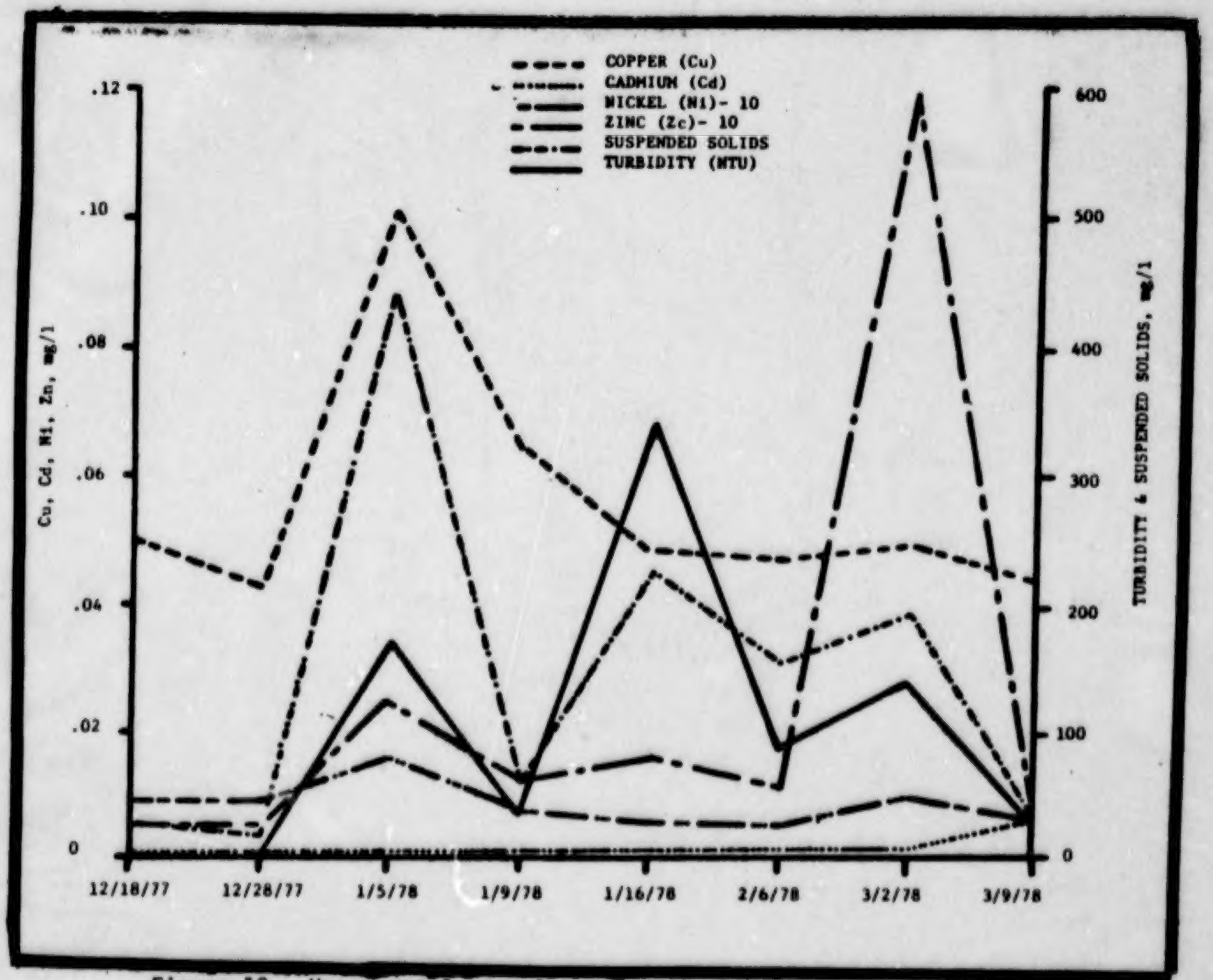

Figure 12. Heavy metal, total suspended solids and turbidity of runoff water from the Sacramento, California sludge application site.

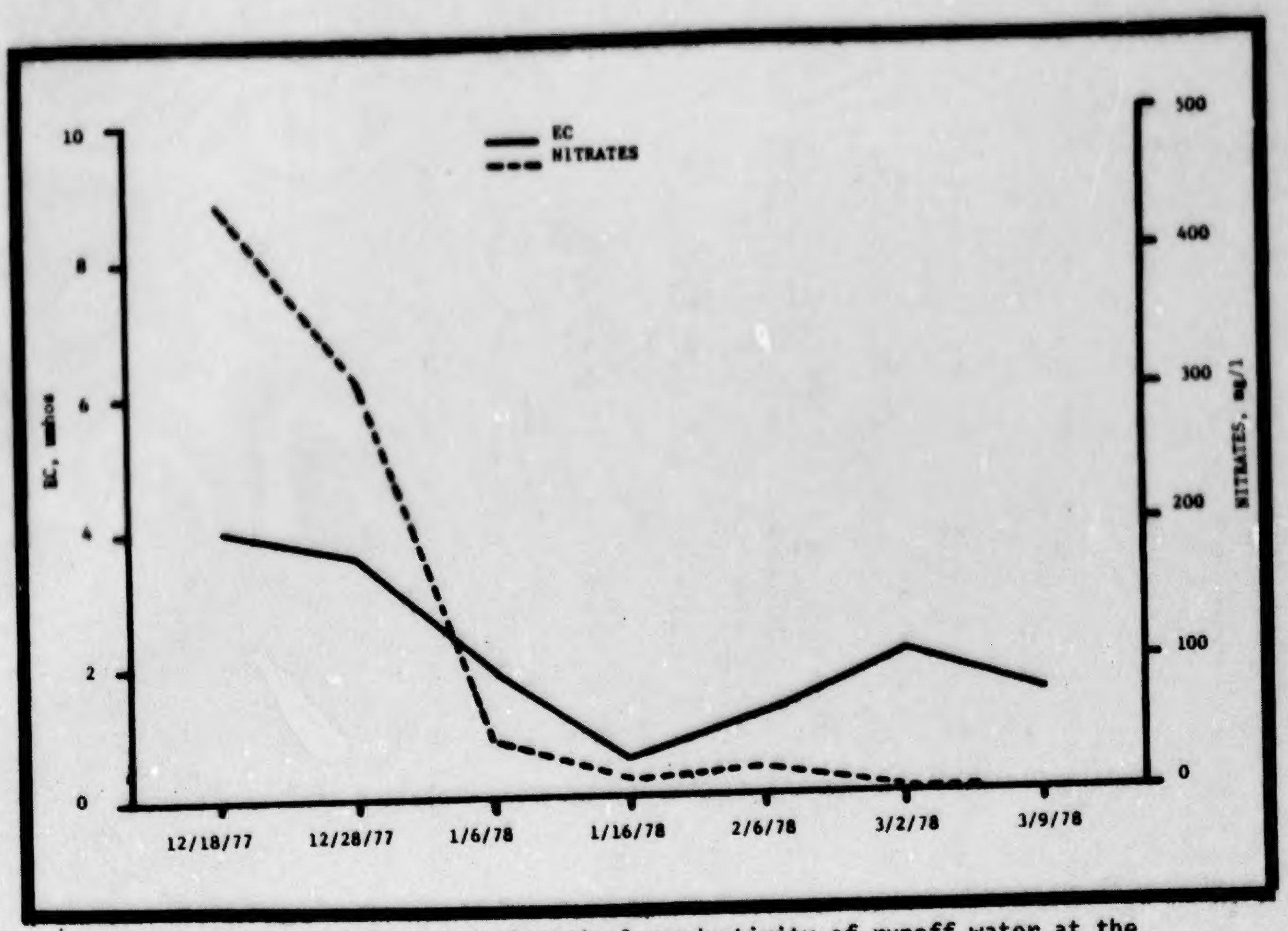

Figure 13. Nitrates and electrical conductivity of runoff water at the Sacramento, California sludge application site.